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Occupational health risk assessment of PC production-caused pollution based on Damage Assessment and Cyclic Mitigation model

Abstract

Purpose – The occupational health risk associated with the production of prefabricated concrete components are often overlooked. This paper will use a Damage Assessment and Cyclic Mitigation (DACM) model to provide individualized exposure risk assessment and corresponding mitigation management measures for workers who are being exposed.

Design/methodology/approach – The DACM model is proposed based on the concept of Life Cycle Assessment (LCA). The model uses Monte-Carlo simulation for uncertainty risk assessment, followed by quantitative damage assessment using DALY. Lastly, sensitivity analysis is used to identify the parameters with the greatest impact on health risks.

Findings – The results show that the dust concentration is concentrated around the mean and the fitting results are close to normal distribution, so the mean value can be used to carry out the calculation of risk. However, calculations using the DACM model revealed that there are still some work areas at risk. DALY damage is most severe in concrete production area. Meanwhile, the Inhalation rate (IR), exposure duration (ED), exposure frequency (EF) and average exposure time (AT), showed greater impacts based on the sensitivity analysis.

Originality/value – Based on the comparison, the DACM model can determine that the potential occupational health risk of PC factory and the risk is less than that of on-site construction. It synthesizes field research and simulation to form the entire assessment process into a casebase system with the depth of the cycle, which allows the model to be continuously adjusted to reduce the occupational health damage caused by production pollution exposure.

Keywords Occupational health; Risk assessment; Construction industry; Prefabricated concrete; Dust

Paper type Research paper

1. Introduction

In 2022, the construction industry accounts for 40% of the world's energy consumption and 39% of the world's CO_2 emissions, reaching a record high (Gonzalez-Torres *et al*, 2022). To achieve zero emissions, efficiency and resiliency in the global construction industry (Chastas *et al.*, 2018; Xu *et al.*, 2023), the prefabricated concrete components (PCs) are being promoted in infrastructure and building construction worldwide. Compared to the conventional cast-in-place construction technique, the PC technique exhibits numerous prospective advantages during production, construction, and installation processes, such as improving efficiency, lowering environmental pollution, and reducing labor requirements and so forth (Katebi *et al.*, 2022; Suarez *et al.*, 2023; Yu *et al.*, 2021)

The PC technique is a series of construction processes in which the designed PCs and modules are manufactured in a factory, transported to the construction site, and assembled on-site to create the final product (Liu *et al.*, 2023). PCs are primarily manufactured in fully or semi-enclosed industrial factories based on the specified dimensions. Current studies focus primarily on increasing production efficiency by optimizing the production line or enhancing product quality. For example, Chang et al. (2021) proposed a discrete differential equilibrium (DDE) algorithm to find optimal solutions such as process time; Qi and Costin (2023) proposed the Designed for Manufacturing and Assembly (DfMA) framework, reducing errors and changes that occur after the design of prefabricated components is finalized, ultimately increasing overall productivity. Minunno et al. (2018) optimized materials, waste, and reuse components for assembled buildings from a cost perspective. Some scholars have also studied from an environmental energy perspective, and Hong et al. (2016) used linear regression analysis to show that the average increment of energy use is almost linearly related to the prefabrication rate. However, scholars have frequently neglected the workers in PC factory. In addition to engaging in strenuous physical labor, workers in PC factories are subjected to specific environments for extended periods of time. During the PC production, workers are perpetually exposed to dust, noise and VOCs, which not only negatively affect the external environment such as the soil, atmosphere, and water, but also pose a threat to the occupational health of workers.

According to relevant literature on the hazardous substances emissions from the construction industry, dust is the primary concern and included in the risk assessment. Inhaling dust may cause sclerosis of the respiratory organs, excessive hemorrhage, cardiovascular disease, cerebrovascular disease, silicosis, and even malignancy. Dust was also chosen as a signature contaminant in the occupational health risk assessment.

Several workplace risk assessment techniques, such as the *Occupational Exposure Limit Assessment and the Supplementary Guidance for Inhalation Risk Assessment* are utilized. The aforementioned traditional deterministic risk assessment considers exposure to dust and other hazards as a dynamic and stochastic risk, which fails to characterize the degree of variability. Contrarily, probabilistic approaches for risk assessment provide more information than deterministic ones in certain risk exposure situations, such as assessing the probability and risk of occupational health resulting from environmental pollution during PC production.

Based on the life cycle assessment, this paper combines the risk assessment process

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with the Monte-Carlo method to assess the uncertainty risk and quantitative damage to workers caused by dust emissions during PC production. Through the sensitivity analysis, the production areas that have a significant impact on health risks were identified. In this way, the Damage Assessment and Cyclic Mitigation (DACM) model was constructed. In this paper, a typical case will be used to validate the DACM model and the corresponding decision optimization ideas are proposed to provide a basis for occupational health management.

2. Literature review

2.1 Dust damage

Meng et al. (2016) conducted a study on dust exposure and its health effects in China, using time-series studies or cohort studies to understand the mortality rate due to dust and to recognize the effects of dust exposure on the human body. During the PC construction process, various dust types are generated, primarily originating from operations and compacting of concrete materials. The most common type is silica dust. When cutting, grinding, or polishing concrete, silica particles are released into tiny dust, posing potential risks to the respiratory tract and lung health (Cheriyan & Choi, 2020; Chao *et al.*, 2023). Normohammadi et al. (2016) used cumulative exposure limits to quantify occupational health risks for demolition workers exposed to silica dust and concluded that this group of workers has a higher risk of lung cancer. Cement, used in concrete production, can generate cement dust during grinding and mixing processes. Aggregates (such as sand, crushed stone, etc.) can produce dust during cutting and compacting operations. Metal dust is often found in iron filings produced during the reinforcement cutting (Zhou *et al.*, 2023). The dust disperses in the air, significantly impacting the respiratory health exposed to such an environment over extended periods. Prolonged dust inhalation can lead to respiratory system diseases including asthma, emphysema, pulmonary fibrosis, and chronic obstructive pulmonary disease (COPD) (Dement *et al.*, 2021; Vested *et al.*, 2021). Inhaling dust increases the cardiovascular diseases risk (Lelieveld *et al.*, 2020). Inhaling metallic dust can cause rare conditions like pulmonary alveolar proteinosis (PAP) (Trapnell *et al.*, 2019). Even prolonged exposure to dust pollution can lead to reduced life expectancy and premature death (Cheriyan & Choi, 2020).

2.2 Occupational health risk assessment

Occupational health risk assessment is the process of identifying and analyzing occupational hazards in the workplace in a comprehensive and systematic manner, predicting occupational health risks, quantifying the level of occupational health risks, and thus taking corresponding control measures (Maragkidou *et al.*, 2017).

There are a number of traditional risk assessment methods currently used in the workplace, and their core principles are largely similar, mostly based on hazard level, exposure level and probability. For example, *Occupational Exposure Limits Evaluation Methodology*, *Supplementary Guidance on Inhalation Risk Assessment*, *International Council on Mining and Metals Occupational Health Risk Assessment Guidance* and so on.

Sajedian et al. (2023) used the *National Institute for Occupational Safety and Health* (NIOSH 1601) to quantify the risk assessment of acrylic vapors and revealed that propylene glycol is much more carcinogenic than the limits. Early models based on regression analysis

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are recommended by Rice et al. (2001) and Mannetje et al. (2002) for assessing the risk of death from lung cancer and silicosis; Cao (2023) used the occupational exposure limit (OEL) as an indicator to assess the current health damage to occupational workers from benzene exposure; Ilbahar et al. (2018) presented the Pythagorean Fuzzy Proportional Risk Assessment (PFPRA) and assessed the risk based on this method during excavation in construction sites. There is uncertainty in the dust exposure due to mobile working conditions. Using the traditional deterministic risk assessment approach, the exposure to dust and other hazards as a dynamic and stochastic risk study target is relatively conservative, and we cannot describe the degree of variability. These studies suggest that construction workers as a whole have higher health risks due to dust exposure. However, these studies fail to compare health risks between different types of activities in construction. (Wang *et al.*, 2022)

In contrast, probabilistic analysis methods can provide more information than deterministic health risk assessment methods. Guo et al. (2022) proposed a dynamic health risk assessment framework (DHRA) to comprehensively assess and reduce the harm caused by dust generated during the renovation construction of polluted industrial buildings; Chen et al. (2019) established a health risk assessment system based on field measurements to reveal the dust risk characteristics of tunnel construction; Zhang et al. (2022) studied the effects of wind speed and water content on dust inhibition rate, drift distance and inhibition rate to provide valuable references for health risk assessment.

2.3 Dust protection measures

Research on mitigating the hazards posed by dust exposure can be categorized into four main approaches: controlling dust emission sources, minimizing dispersion, reducing worker exposure, and enhancing regulatory oversight and assessment. Nij et al. (2003) indicated that a combination of LEV and water dust suppression can reduce dust emissions by up to 80% when working on limestone sandstone. Fan et al. (2012) used the NIOSH 0600/7500 method to monitor concrete drilling activity on concrete blocks and measured dust exposure generated and emitted with and without controls, ultimately finding that the DustBubbles method reduced respirable dust exposure by 63%. Zhang et al. (2022) suggest that during the engineering design phase, production processes optimization and workshop layouts, measures like enclosed transportation, isolated operations, and centralized dust collection can effectively reduce dust pollution. Cheriyan & Choi (2020) recommend selecting low-dust emission production equipment, reducing dust generation at the source, and conducting regular maintenance. Mwaiselage et al. (2004) propose the standardized operating procedures based on job characteristics, such as packaging requirements for cement or pouring concrete sequences, to minimize dust generation. Hong et al. (2019) proposed a conceptual framework for real-time monitoring of emissions, including dust emissions from construction works, which can help to reduce exposure using effective control measures based on different dust exposure profiles from different activities. Ervik et al. (2022) emphasize designing appropriate layouts and ventilation systems for production areas, increasing ventilation frequency, using new fans to enhance air exchange efficiency, and preventing dust accumulation. Li et al. (2019) generated a dataset including most of the dust-generating construction activities (i.e., cement mixing, drilling, excavating, sanding,

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cutting, etc.) performed at construction sites for analysis. The results of the study indicated that existing control measures are not sufficient to reduce PM exposure to healthy levels.

2.4 Summary

Based on the literature review, occupational workers exposed to dust for long periods of time are at increased risk of asthma, pneumoconiosis, chronic obstructive pulmonary disease, and cancer, and that the factors influencing the manifestation of disease symptoms in workers are related to the source of dust, the intensity and duration of exposure, and the workers own physical status, and that these influencing factors need to be prioritized for management.

In terms of exposure risk assessment methods, traditional deterministic assessment methods are not applicable due to the unclear characteristics of dust dispersion and the wide range of workers' activities in the PC production process. Most of the existing probabilistic risk analyses target traditional construction sites and take different construction sites as examples for health risk evaluation. But because traditional project construction usually lasts two to three years. It is not complete there is dust exposure and possible to re-test the effects of the proposed measures and subsequent mitigation. In contrast, PC production workers work in a fixed plant since the beginning. Workers are responsible for a particular job on the production line, there is little mobility of work types, exposure frequency and specific contaminants are more fixed, and the project content may change but the work remains the same always in contact with concrete dust. It is emphasized in risk management that risk assessment and treatment should be dynamic and continuously repeated activities to deal with changes in the project environment and the risks themselves. Therefore, it is necessary to construct an occupational health risk model that can be adapted to phase workers in fixed exposure environments, and that is capable of periodic phase health risk assessment and adjustment of health risks.

3. Methods

This study refers to the risk assessment guidelines of the *United States Environmental Protection Agency (USEPA)*, transforming raw data into risk quantification to describe probability, and ultimately dividing the assessment into three processes: hazard identification, dose response assessment, and exposure risk assessment.

3.1 Hazard identification

The study links hazard identification with exposure science, limiting the scope of identification to the continuous exposure of affected populations (occupational workers) to hazardous substances during the production of PCs (Ervik *et al.*, 2022). The PC production line consists of ten major processes. Since concrete and steel bars are the raw materials of PCs, dust matters are produced during the manufacturing process, including silicon dust, cement dust, saw dust, and steel scrap. According to the exposure source, the aforementioned production process is divided into seven work areas. Inhalation, ingestion and dermal contact are three major routes of exposure to hazardous substances in the exposed environment. Inhalation is considered to be the primary route of exposure to dust. The specifics of the division and respiratory pathway are illustrated in Figure 1.

3.2 Dose-response assessment

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The potential exposure doses for inhalation can be quantified by multiplying the agent concentration by the exposure duration (Anttila *et al.*, 2022). Since PC production dust is non-carcinogenic, the average daily dose (ADD) is used as an evaluation index (Equation 1) (Shao *et al.*, 2018).

$$ADD = \frac{C \times IR \times ED \times EF \times ET}{BW \times AT} \quad (1)$$

where ADD denotes the average daily exposure dose (mg/(kg·d)) for PC production workers, C is the concentration of dust in each work area (mg/m^3), IR is the inhalation rate for adults (m^3/h), ED is the exposure duration (a), EF is the exposure frequency (d/a), ET is the exposure time (h/d), BW is the body weight (kg), and AT is average exposure time (d).

IR parameters vary among workers with various positions and varying levels of labor intensity. To deal with the unpredictability, Monte-Carlo simulation of risk probability is implemented which is essentially repeated sampling from the probability distributions of multiple input variables to generate a distribution of output variables. It has been demonstrated that predictions can remain relatively stable after approximately 4,000 simulations, whereas more accurate after over 10,000 simulations and can be constructed with mean standard errors and appropriate confidence intervals (Aghvami *et al.*, 2023).

3.3 Exposure risk assessment

Typically, equation 2 is used to assess the risk to occupational health, where R represents the health risk posed by dust, RfD denotes the reference dose of dust. Note that the RfD of PC dust has not been determined; rather, R can be calculated indirectly by a relevant substance of Dibutyl Phthalate, whose RfD is known (Wang *et al.*, 2022). The RfD for PC dust is ultimately determined to be 0.4 mg/(kg·d) (Tong *et al.*, 2018).

$$R = \frac{ADD}{RfD} \quad (2)$$

The disability-adjusted life year (DALY) is the primary instrument for quantifying the burden of disease and injury on humans, which can be estimated according to different perspective, including, incidence (I-DALY), pure prevalence (PP-DALY), or a hybrid perspective (H-DALY) (Schroeder, 2012).

I-DALY begins with the incidence rate, determines the prevalence of this type of event during the target time period, and then adds the DALY in these time periods. Pneumoconiosis, chronic obstructive pulmonary disease (COPD), cerebrovascular disease (CVD), vascular heart disease, acute respiratory infection, and death are currently among the health hazards posed by construction dust (Go *et al.*, 2020; Vested *et al.*, 2021; Onder *et al.*, 2021). The aforementioned hazards can be quantified using I-DALY, as shown in Equation (3).

$$I - DALY = n \times \sum R \times Q_i \times W_i \times L_i \times P \quad (3)$$

where Q_i represents the risk factor of disease i, W_i represents the effects the effect factor of disease i, L_i denotes the damage factor of disease i, P represents the number of persons affected by the damage, and n represents exposure days, which is equal to the construction period.

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3.4 Damage Assessment and Cyclic Mitigation Model

Based on the above three risk management processes, the DACM model was developed, as depicted in Figure 2. The DACM model is based on risk management theory and targets occupational workers of PC factories in different areas, utilizing the cycle as a vertical progression to determine risk. In the risk identification phase, the exposure source and the exposure type are defined, and in this study at the PC plant the main study exposure substance was dust. The exposure source is production equipment and materials in the work areas, and the exposure type is primarily by the inhalation route. The exposure target group was occupational workers and the parameters were mainly exposure parameters. After field measurements to sample the data, the uncertain data results were subjected to Monte-Carlo simulation, and the measured dust was converted into human inhalation concentrations using dose-response assessment. In the exposure risk assessment stage, the results of the inhalation concentration are used to evaluate the occupational health exposure risk, calculate the occupational health risk, and derive a comparable risk index and the corresponding I-DALY value. Finally, a sensitivity analysis is performed to identify key impact parameters or factors. A loop is added at the decision optimization service to combine field research, simulation modeling, and measure analysis. Field research (FR) is the physical entity, simulation (SL) is the virtual entity, and measures (M) is the service. Through field research to increase the number of cases, and simulation-derived statistics to adjust each other for the existence of risk areas for the key impact parameters development to adjust the measures, put forward a targeted strategy to summarize, the formation of a recyclable case base (CB). After such dynamic measures are adjusted to enter the second cycle, the model is regularly implemented to continue the cycle of periodic phase in-depth occupational health risks management, which will be discussed in more depth in the discussion section.

4. Case study

4.1 Dust sampling and preparation

The case study is a PC factory in Nanjing, China, which has an excellent management system, production compliance and is in the state of order production. The specific sampling preparation process is described below:

Sampling preparation. The factory is semi-open, east-west ventilated, and adopts the typical and high efficiency assembly line mode of "double-in, double-out". From supporting to dismantling the whole process, the PC production is always in the same construction line in accordance with the U-shaped layout, the reason is that in the lower part of the motorized transporter on the mold tables for the transport needs to be kept in the same transport line. This study is based on field records and information provided by factory managers about the work of laborers (including the number, mode of operation, work routes and duration, frequency, etc.). The PC production process is relatively independent and is ultimately standardized by production equipment and work patterns, which group production equipment and workers for the same work purpose into a single work area. There is no dust removal system in the production facility, most of the production workers are not wearing masks, and the workers in each work area work basically the same number of hours and are all potentially exposed to dust. The outdoor work area is divided into a separate work area for comparison with the indoor area. The specific structure and process shown in Figure 3

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model diagram.

Sampling strategy. The measuring instrument is a portable continuous sampling instrument, which is based on the principle of applying the filter membrane weighing method to capture pollutant dust in the ambient atmosphere and display the measurement results digitally. The sampling method refers to *the Specification for Air Sampling for Hazardous Substances Monitoring in the Workplaces (GBZ 159-2004)* for evaluative short-time fixed-point sampling. According to the regulations, when there are more than two different types of production equipment in a work area, escaping the same hazardous substance, the sampling point shall be set at the work point near the equipment with the larger concentration of the escaped hazardous substance. There are approximately four pieces of production equipment in each work area in the field, so three to four locations in the work area where workers are more active are selected as sampling points. Multiple consecutive samples are taken throughout the day based on exposure periods, with multiple samples taken within a day, but the sum of the sampling time equals the number of hours worked by the operator in a day.

In order to ensure that the sample results of the same work area in the same time period can be cross-referenced, so the same work area randomly selected two sampling points at the same time to measure, set up a tripod to ensure that the instrument air inlet and the worker's work respiratory belt at the same height. Two work areas for a group, a single sampling time of 15 minutes for a group of four consecutive measurements. And then replace the other group for sampling, repeat the operation after a round, replace the sampling point to measure again, measured until the workers leave the work area on a working day, three consecutive days of measurement. One of the outdoor deployment of transportation work area because it is in the outdoor and indoor comparison for all-day measurement. In this study, Crystal-Ball software was used to fit the distributions of the parameters and the above measurements in the Methods section. In order to validate the distribution of the observed data, this study use the K-S (Kolmogorov-Smirnov) test, which is based on the difference between the observed values and the cumulative distribution function to assess whether the observed data come from the hypothesized distribution.

Parameter selection. The parameters associated with DALY related parameters can be allocated proportionally, where L_0 is the standard average remaining life expectancy of workers; since pneumoconiosis is generally difficult to be cured, its duration is L_0; the per capita life expectancy of Chinese residents is 78.2 years (NBSPRC, 2021). The ADD and DALY-related parameters are summarized in Table 1 and Table 2.

Combined with dust sampling and according to China's "*Occupational Exposure Limits for Hazardous Factors in Industrial Premises*" (GBZ 2-2007) dust (concentration/limit value) are defined as follows, 0.2-0.5 mg/m^3 is satisfactory, 0.5-1.0 mg/m^3 is fair, 1.0-1.5 mg/m^3 is poor, mold support and mold removal area is evaluated as fair, all other parts exceed the 1.0 mg/m^3 limit, and components pre-embedding and reinforcement tying, concrete pouring and concrete vibration, reinforcement cutting and welding and concrete production are evaluated as poor. However, the dust limits only indicate that the dust samples measured exceeded the standard, but it is not possible to determine the occupational health risk due to dust acting on the human body through the inhalation route, and therefore needs to be further explored using the DACM model.

4.2 *Case results of applying the DACM model*

The fitting distribution results of dust concentration and some statistical values are shown in Table 3. Among them, the results for mold support and mold removal, components pre-embedding and reinforcement tying, concrete pouring and concrete vibration, reinforcement cutting and welding, as well as concrete production conform to the log-normal distribution. The normal distribution is suitable for component maintenance and outdoor deployment and transportation. The p-values for these fitting results have all passed the Kolmogorov-Smirnov test.

Analyzing the overall state of the distributions, it's observed that the work areas kurtosis involved in mold support and mold removal, components pre-embedding and reinforcement tying, reinforcement cutting and welding, and concrete production are all greater than 3.00. The peaks of these distributions are sharper compared to a normal distribution, indicating a higher concentration of data points near the peaks and fewer data points in the distribution tail. In this scenario, the distribution tails might be relatively light, implying a lower probability far from the mean. The data skewness for concrete pouring and concrete vibration, as well as reinforcement cutting and welding, is close to zero, indicating a relatively symmetric distribution on both sides.

The skewness for mold support and mold removal, and components pre-embedding and reinforcement tying are both positive and relatively small, suggesting a balanced distribution on both sides of the mean. The tail shape of these distributions might approximate the tail of a normal distribution without excessive extension. Despite some degree of skewness, the overall data distribution remains relatively stable in the central region, and significant outliers or extreme values are less likely to exist. It's worth noting that the positive and relatively large skewness of the concrete production area indicates a slight rightward skew of the data distribution. The tail on the right side of the mean is relatively longer, while the left tail is shorter. This might suggest the presence of some outliers slightly above the data average. Therefore, when calculating values for the concrete production area, special attention will be given to outliers, and they will be assigned to the nearest interval for binning. Nevertheless, the data is stably distributed in the central region. The small variability indicated by the dispersion of variance suggests that the log-normal distribution data has little variation, with most data centered around the mean.

Therefore, we believe that the average dust concentration in the PC production can be used to calculate the risk value. This can be compared with the risk value calculated using subsequent uncertainty parameters.

Risk thresholds were calculated for dust concentrations in this study defining a risk of 10^{-6} or less as an acceptable and negligible risk: a value of 10^{-4} or greater as a substantial risk; and a value of 10^{-6}~10^{-4} as a potential risk (Liao and Chiang, 2006). Table 4 shows the results of the health risk assessment and potential health harm caused by dust in each work area during the PC manufacturing phase. From the perspective of the average value concrete III and VII areas exceeded the risk thresholds, while II and VI areas had the possibility of exceeding the risk thresholds in the percentile points, and other work areas did not reach the thresholds in terms of the risk values. For better validation of the model results, certainty risk value was calculated based on the mean value of dust concentration and the possible values of the parameters. The health risk assessment results are shown in Figure 4. We can show that the boxed portions of the III and VII areas exceed the risk thresholds, the intervals in the VII area span a wide range but the vast majority of the intervals exceed the risk thresholds, and the III area of the distribution is denser but also exceeds the risk value intervals, suggesting that there is a very high probability of risk exposure in these two areas. While the II and VI areas with the upper whiskers have exceeded the risk thresholds, compared to certainty risk values calculated from the average value of the dust concentration, finding the risk values different from the average results. The risk values of the other work areas do not reach the thresholds.

Sensitivity analysis depicted in Figure 5 shows that AT, EF, and ED have a greater impact on dust health risks. In the VII area, AT, EF, and ED were -48%, 49%, and 47%, respectively, and in the III area, AT, EF, and ED were -47%, 47%, and 45%, respectively. C had the greatest impact on the dust health risk during the VI area, with a sensitivity of 57%, and AT, EF, and ED were -40%, 38%, and 37%, respectively. The AT and BW parameters showed a negative correlation, with the sensitivity of the BW parameter much lower than that of the AT parameter. Among the parameters that showed a positive correlation, EF and ED consistently occupied a greater sensitivity, indicating that the time that workers work has a strong influence on dust exposure and that measures should be taken to reduce health risks. In the VI area, the effect of concentration is greater than the effect of other parameters.

DALY provides a quantitative indicator of dust health damage, visualizes the damage to the human body, and can be used to increase stakeholders' focus on dust protection in comparison to health risk values. Figure 6 reflects the DALY damage in four activity areas with dust exposure risk, with the years of loss and disability ranging from 2×10^{-4}a to 5.65×10^{-1}a. The probability diagram of DALY damage distribution for each working area is shown in the Figure 7. The DALY values of workers in VII and VI areas are greater than those of workers in the other two areas. Among them, the DALY value for concrete production ranges from 1.3×10^{-3}a to 5.65×10^{-1}a, which indicates a relatively hazardous range. Therefore, in addition to dust prevention measures, it is necessary to conduct routine physical examinations to monitor the health of workers and promptly alleviate or treat discomfort feelings.

5. Discussion

5.1 Risk assessment analysis due to dust

Risk assessment needs to consider not only the relationship between probability and consequence, but also focus on the uncertainty effect caused by the variables involved. From the fitted statistical results, it can be shown that the dust concentrations follow the probability characteristics of normal distribution, and although the risk assessment can be carried out by means value, there are still some areas with probabilistic risk. The risk value varies depending on the working conditions in different work areas, leading to significant differences in the outcomes. According to the risk assessment results, the occupational health risks due to dust exposure are: concrete production, concrete pouring and vibration, reinforcement cutting and welding, component pre-embedding and reinforcement tying.

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From the model diagram in Figure 3, it can be understood that in order to speed up the construction efficiency, the reinforcement cutting was placed near the assembly line, the reinforcement processing area is located in the center of the factory where ventilation is inadequate, resulting in the accumulation of dust. Additionally, reinforcement cutting requires driving mechanical vibration and causing the spread of deposited dust. Producing concrete may cause the spread of dust over a large area, so separate isolation is required. The PC transportation area is located in an open field, the dust concentration can be reduced when the road dust reduction and spraying is conducted effectively. The component maintenance is completely enclosed by curing boxes around the components, while water vapor inhibits the diffusion of dust to the adjacent areas and lowers dust concentration. The mold support and removal area situated at both ends of the assembly line near outdoor ventilation experiences a low dust concentration due to limited material processing technology. The components pre-embedding and reinforcement tying area must be strengthened via crawler transportation and striking, resulting in a certain dust concentration; Dust is generated in the concrete pouring and vibration area due to the periodic vibration of the vibrating table and the rod.

5.2 Decision optimization for DACM models

The variability of the dust exposure risk environment present in PC factory confirms that the DACM model can be well assessed from an uncertainty risk perspective. In comparison with the uncertain dust exposure risk assessment of the construction site studied by Tong et al. (2018), the DALY damage suffered by the workers in the PC factory was less than that suffered by the workers in the construction site who performed ready-mixed concrete construction. This also indicates to some extent that assembled buildings have certain advantages in the occupational health protection for workers.

The DACM model aims to simulate the periodic control of occupational health risk due to environmental emissions. The model combines simulation and field studies to quantify worker health damages, assess the parameters sensitivity, and develop appropriate risk assessment measures. In order to better protect this group, and in continuation of the USEPA evaluation guide, this study discusses the DACM model in more depth and includes such a conceptual framework in the decision optimization cycle. The field research (FR) shown in the framework is the physical entity, simulation (SL) is the virtual entity, measures (M) is the service, and case base (CB) is the database.

The FR in the physical layer serves as an entity for factor identification and data acquisition. And accurate sampling of the FR is the basis for building the simulation model. A single working area can be regarded as a unit-level FR, which is a basic unit including the overlapping functions of four parts: Human-Material-Machine-Environment; a whole set of production line can be regarded as a system-level FR, which can fulfill the component production tasks; the whole factory consisting of the production line, the environmental emissions and the workers can be regarded as a comprehensive systematic FR including the material flow, emission flow and information flow. This study focused on a single PC work area as a unit level to study, and finally the whole set of PC process of different unit level for comparison to screen out the whole system-level risk probability of FR.

SL is formulated according to the rule construction, which is the core of the

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establishment of the virtual layer. The modeling system of this research case is a series of mathematical concepts from fitting the data distribution, to the composition of parameters in the risk calculation, and finally to the damages quantification, with reference to the USEPA's assessment guideline, as well as the Monte-Carlo methodology based on the simulation of the data for the uncertainty risk exploration. The system should also include geometric, behavioral and rule-based models. Based on this case study, each physical entity in the PC production process will be described and portrayed from multiple time and spatial scales in conjunction with the sensitivity analysis. This facilitates a more detailed portrayal of the dust exposure principle, and realizes that PC factory in different environments can be evaluated using a universal evaluation model, but with unique evaluation results.

The service layer mainly ensures the integration of measure functions and modules. The service layer aims to synthesize various types of data, models, algorithms and results in the DACM model to support the operation of the model functions and to provide functional measure services. In this case the main service is related to the management decision makers in PC production for information acquisition on dust environmental releases and worker health risks. It is analyzed as follows:

(1) Information from the data collected through the risk identification process indicates that the average age of the workforce is 41 years old and the average number of years in the workforce is 20 years. Long-term production operations accompanied by continuous dust exposure exacerbate health risks; (2) As the sensitivity analysis, inhalation, as the only way for dust to enter the body, was positively correlated with the inhalation rate (IR) of the operator and increased with increasing intensity. Workers are exposed for a long time, because of the one-shift work system, the work intensity is too high, and physical injuries cannot be repaired immediately. The risks associated with this will be exacerbated if ventilation is not improved in a timely manner or workers' work frequency is adjusted; (3) The conclusions drawn from the damages quantification are that dust exposure is damaging to workers to varying degrees in different work areas, more so in areas where the risk of dust exposure is higher, and that the damage increases with time; (4) The relatively high concentrations in the reinforcement cutting and welding area, as deduced from the FR, may be due to its central location in the production hall. This arrangement facilitates interaction with reinforcement tying and reduces transportation capacity and safety risks. However, it leads to dust generation, which increases occupational health risks due to inadequate ventilation; (5) The concrete production area requires machines to transport raw materials such as sand and gravel for concrete production. Also, concrete generates a large amount of dust during mechanical processing and mixing, which increases the dust concentration.

A number of measures are provided at this level to reduce the occupational health risks of dust to workers. In the outdoor deployment and transportation and component maintenance areas, there are almost no dust and the health risk is acceptable. A low potential risk exists during component pre-embedding and reinforcement tying. Therefore, basic dust control measures are necessary. Work in the concrete production and reinforcement cutting and welding areas poses the most damaging health risks to workers. Vibrations from rebar cutters and continuous spot-welding machinery result in the dispersion of rebar chips and dust. Therefore, the implementation of dust monitoring facilities at designated locations, pre-

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wetting of floors, the use of dust collectors to separate dust from air, and investment in the development of new dust control technologies. Develop a dust prevention plan, establish a monitoring and surveillance system, and strengthen healthcare programs. Appropriate subsidies are provided from the perspective of organizational management, and to mitigate the risks posed by this parameter, it is recommended that dust removal equipment be increased or workshop processes be upgraded. It is recommended to adopt a job rotation system and to rationalize shifts and organize production taking into account the age of the workers. From a personal point of view, it is important to raise the safety awareness of occupational workers by requiring them to wear dust protection equipment.

After the establishment of the above layers, the layers are connected together through the addition of formulas and software to ensure that the model can be summarized into the final database (DB) through operation. This is like a screw, from a separate cycle gradually progressive and finally form a regular whole, the establishment of the final data layer database is the key to realize the linkage and transmission of information between the layers. It mainly includes FR data, SL data and M data, and this kind of data allows PC factory in different construction environments to interconnect in the data layer.

This not only enables the use of the DACM model in a single assessment, but after this it can be used in a continuous cycle of self-improvement of the model through later software enhancements and expansion of sample types. The lifecycle concept can be deepened through periodic phase integration and iterative optimization of worker health data. Decision makers can continuously upgrade monitoring programs such as monitoring points, thresholds and work areas, according to the characteristics of environmental emissions and occupational health risks in different PC factory environments. In this way, a time-dynamic evaluation with strong timeliness and universality can be formed to realize a health risk management strategy that balances economic benefits, environmental emissions and health risks.

6. Conclusion

This study constructs a DACM model to quantify the occupational health impact of dust on workers involved in the production of PCs. Firstly, the PC factory is divided into seven work areas, and exposure sources and targets are determined based on the risk identification. Then, according to the on-site sampling, the probability distribution of exposure parameters and dust concentration was provided. Thirdly, the Monte-Carlo method was used to calculate the health risks of workers exposed to dust in various work areas, based on the LCA concept. The results showed that concrete production>concrete pouring and vibration>reinforcement cutting and welding>reinforcement tying and components pre-embedding>mold support and removal>PC maintenance>outdoor deployment and transportation. Additionally, the sensitivity analysis revealed that AT, ED, EF and IR had a greater impact on health risk assessment in the calculation parameters. Finally, DALY damage to work areas with risks is quantified. Dust poses the greatest threat to the health of workers in concrete production phase. Urgent and effective measures should be taken to protect their health.

The findings may increase social attention to the occupational health of prefabricated construction industry, and provide valuable information about the impact of worker health

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hazards and damage. The risk assessment is presented as probability distributions, making it more scientific and comprehensive. Furthermore, the I-DALY indicator facilitates the understanding of health damage, and the results contribute to the development of compensation policies of workers. However, the risk assessment process contains uncertainties. For example, the RfD provided by the USEPA is the risk of not having 1 mg/m^3 continuous exposure to pollutants assuming a 70 kg adult breathes 20 m^3/day, while the Chinese Population Exposure Parameters Handbook provides a long-term inhalation rate of 15.7 m^3/day. In order to develop a more accurate assessment framework, future studies will examine more PC factory, with cyclic conditioning according to the DACM model and the creation of a database. In this study, the risk profile and causal parameters were investigated using the DACM model to focus on inhalation of dust concentrations during the field measurement of the sample phase versus the worker's work throughout the day. However, the temporal perspective did not allow a more detailed differentiation of which of the two types of dust, the re-emergence of old dust due to the operation of the equipment and the new dust generated by the construction of the material, is more serious in terms of worker health risk, and this will be one of the areas where we can improve our measures. In a follow-up study, we will use CFD fluid concepts to examine this time-span study point of old and new dust in more detail.

Author Contributions

PC led the overall study. RQ, ZD and PZ conducted the site survey. ZD, XY and FZ conducted the analysis and drafted the manuscript with input from the other authors. YY helps to provide the research site. All authors contributed to the concept and design of the study, the interpretation of data, revision of the manuscript for important intellectual content, and have read and approved the final version of the manuscript.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

Data availability statement

Collected data and research protocol are available from the corresponding author on reasonable request.

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Reference

Aghvami, M., Mohammadi, A. and Khaniki, G.J., *et al.* (2023), "Investigation of cocoa and cinnamon effect on acrylamide formation in cakes production using GC/MS method: A risk assessment study", *Food Chemistry: X*, Vol.18, 100629. https://doi.org/10.1016/j.fochx.2023.100629.

Anttila, A., Uuksulainen, S. and Rantanen, M., *et al.* (2022), "Lung cancer incidence among workers biologically monitored for occupational exposure to lead: a cohort study", *Scandinavian Journal of Work Environment*, Vol.48 No. 7, pp. 540-548. https://doi.org/10.5271/sjweh.4046.

Arastoo, H., Hakimovich, A.P., and Esfandiarpour, S. (2015), "Assessment of barriers to establish OSH: a country report", *Industrial health*, Vol.53 No. 4, pp. 378-384. https://doi.org/10.2486/indhealth.2013-0234.

Bakke, B., Ulvestad, B. and Stewart, P., *et al.* (2004), "Cumulative exposure to dust and gases as determinants of lung function decline in tunnel construction workers", *Occupational and Environmental Medicine*, Vol.61 No. 3, pp. 262-269. http://dx.doi.org/10.1136/oem.2003.008409.

Cao, Y., Wang, T. and Xi, J., Tian, *et al.* (2023), "Benchmark dose estimation among benzene-exposed workers in China: Based on quantitative multi-endpoint genotoxicity assessments", *Environmental Pollution*, 121765. https://doi.org/10.1016/j.envpol.2023.121765.Chang, C., and Han, M. (2021), "Production scheduling optimization of prefabricated building components based on dde algorithm", *Mathematical Problems in Engineering*, Vol. 2021, 6672753. https://doi.org/10.1155/2021/6672753.

Chao, Z., Dang, Y., Pan, Y., et al. (2023), "Prediction of the shale gas permeability: A data mining approach", *Geomechanics for Energy and the Environment*, Vol.33, 100435. https://doi.org/10.1016/j.gete.2023.100435.Chastas, P., Theodosiou, T. and Kontoleon, K.J., *et al.* (2018) "Normalising and assessing carbon emissions in the building sector: A review on the embodied CO2 emissions of residential buildings", *Building and Environment*, Vol. 130, pp. 212-226. https://doi.org/10.1016/j.buildenv.2017.12.032.

Chen, X.F., Guo, C. and Song, J.X., *et al.* (2019) "Occupational health risk assessment based on actual dust exposure in a tunnel construction adopting roadheader in Chongqing, China", *Building and Environment*, Vol. 165, 106415. https://doi.org/10.1016/j.buildenv.2019.106415.

Cheriyan, D., and Choi, J.H. (2020) "A review of research on particulate matter pollution in the construction industry", *Journal of Cleaner Production*, Vol. 254, 120077. https://doi.org/10.1016/j.jclepro.2020.120077.

Dement, J.M., Cloeren, M. and Ringen, K., *et al.* (2021) "COPD risk among older construction workers—Updated analyses 2020", *American Journal of Industrial Medicine*, Vol.64 No. 6, pp. 462-475. https://doi.org/10.1002/ajim.23244.

Ervik, T.K., Hammer, S.E. and Noto, H., *et al.* (2022) "Physicochemical characterization of particulate matter in a cement production plant", Environmental Science: Processes & Impacts, Vol. 24 No. 8, pp. 1243-1256. https://doi.org/10.1039/d2em00139j.

Fan, S., Wong, Y. W. and Shen, L., et al. (2012) "The effectiveness of DustBubbles on dust control in the process of concrete drilling", *Safety science*, Vol. 50 No. 5, pp. 1284-1289. https://doi.org/10.1016/j.ssci.2012.01.001.

Go, L.H.T. and Cohen, R.A. (2020) "Coal Workers' Pneumoconiosis and Other Mining-Related Lung Disease: New Manifestations of Illness in an Age-Old Occupation", *Clinics in chest medicine*, Vol. 41

No. 4, pp. 687-696. https://doi.org/10.1016/j.ccm.2020.08.002.

Gonzalez-Torres, M., Perez-Lombard, L. and Coronel, J.F., et al. (2022) “A review on buildings energy information: Trends, end-uses, fuels and drivers”, *Energy Reports*, Vol. 8, pp. 626-637. https://doi.org/10.1016/j.egyr.2021.11.280.

Guo, J., Liu, Y. and Hu, C., et al. (2023) “Long-term exposure to dust and noise can increase the risk of hypertension-a population-based, cross-sectional study”, *Journal of Occupational and Environmental Medicine*, Vol. 65 No. 3, pp. 128-133. https://doi.org/10.1097/JOM.0000000000002769.

Guo, P., Tian, W. and Li, H.M. (2022) “Dynamic health risk assessment model for construction dust hazards in the reuse of industrial buildings”, *Building and Environment*, Vol. 201, 108736. https://doi.org/10.1016/j.buildenv.2021.108736.

Hong, J., Hong, T. and Kang, H, et al. (2019) “A framework for reducing dust emissions and energy consumption on construction sites”, *Energy Procedia*, Vol. 158, pp. 5092-5096. https://doi.org/10.1016/j.egypro.2019.01.637.

Hong, J., Shen, G. Q. and Mao, C., *et al.* (2016) “Life-cycle energy analysis of prefabricated building components: an input–output-based hybrid model”, *Journal of Cleaner Production*, Vol. 112 No. 4, pp. 2198-2207. https://doi.org/10.1016/j.jclepro.2015.10.030.

Ilbahar, E., Karaşan, A. and Cebi, S., *et al.* (2018) “A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system”, *Safety science*, Vol. 103, pp. 124-136. https://doi.org/10.1016/j.ssci.2017.10.025.

Katebi, A., Homami, P. and Najmeddin, M. (2022) “Acceptance model of precast concrete components in building construction based on Technology Acceptance Model (TAM) and Technology, Organization, and Environment (TOE) framework”, *Journal of Building Engineering*, Vol. 45, 103518. https://doi.org/10.1016/j.jobe.2021.103518.

Lelieveld, J., Pozzer, A. and Pöschl, U., *et al.* (2020) “Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective”, *Cardiovascular Research*, Vol. 116 No. 11, pp. 1910-1917. https://doi.org/10.1093/cvr/cvaa073.

Li, C. Z., Zhao, Y., and Xu, X. (2019) “Investigation of dust exposure and control practices in the construction industry: Implications for cleaner production”, *Journal of Cleaner Production*, Vol. 227, pp. 810-824. https://doi.org/10.1016/j.jclepro.2019.04.174.

Liao, C.M., Chiang, K.C. (2006) “Probabilistic risk assessment for personal exposure to carcinogenic polycyclic aromatic hydrocarbons in Taiwanese temples”, *Chemosphere*, Vol. 63 No. 9, pp. 1610-1619. https://doi.org/10.1016/j.chemosphere.2005.08.051.

Liu, C., Zhang, F.Q. and Zhang, H., *et al.* (2023) “Optimization of assembly sequence of building components based on simulated annealing genetic algorithm”, *Alexandria Engineering Journal*, Vol. 62, pp. 257-268. https://doi.org/10.1016/j.aej.2022.07.025.

Makki, A.A. and Mosly, I. (2020) “Determinants for Safety Climate Evaluation of Construction Industry Sites in Saudi Arabia”, *International Journal of Environmental Research and Public Health*, Vol. 17 No. 21, pp. 8225. https://doi.org/10.3390/ijerph17218225.

Makki, A.A. and Mosly, I. (2020) “Determinants for safety climate evaluation of construction industry sites in Saudi Arabia”, *International journal of environmental research and public health*, Vol. 17 No.21, 8225. https://doi.org/10.3390/ijerph17218225.

Mandowa, J., Matsa, M. and Jerie, S. (2022) “A global review of implementation of occupational safety and health management systems for the period 1970-2020”, *International Journal of Occupational Safety* *and Ergonomics*, Vol.29 No.2, pp. 821-836. https://doi.org/10.1080/10803548.2022.2083811.

Maragkidou, A., Arar, S. and Al-Hunaiti, A., *et al.* (2017) "Occupational health risk assessment and exposure to floor dust PAHs inside an educational building", *Science of The Total Environment*, Vol. 579, pp. 1050-1056. https://doi.org/10.1016/j.scitotenv.2016.11.055.

Meng, J., Liu, J. and Fan, S., et al. (2016) "Potential health benefits of controlling dust emissions in Beijing", *Environmental Pollution*, Vol. 213, pp. 850-859. https://doi.org/10.1016/j.envpol.2016.03.021.

Minunno, R., O'Grady, T. and Morrison, G.M., *et al.* (2018) "Strategies for applying the circular economy to prefabricated buildings", *Buildings*, Vol. 8 No. 9, p. 125. https://doi.org/10.3390/buildings8090125.

Mwaiselage, J., Bråtveit, M. and Moen, B., et al. (2004) "Cement dust exposure and ventilatory function impairment: an exposure-response study", *Journal of occupational and environmental medicine*, pp. 658-667. https://www.jstor.org/stable/44997350.

National Health and Family Planning Commission of the people's Republic of China. (2014) Specification for Air Sampling for Hazardous Substances Monitoring in the Workplaces (GBZ 159-2004). Available at: http://www.nhc.gov.cn/zwgkzt/pyl/201412/23d80783145a44b998bd0a0f122e9f87.shtml. [Accessed 2023 Oct 18th].

NBSPRC. (2021) Statistical bulletin of the development of China's health care industry in 2021. Available at: http://www.stats.gov.cn/english/PressRelease/202102/t20210228_1814177.html. [Accessed 2023 Apr 25th].

Normohammadi, M., Kakooei, H. and Omidi, L., et al. (2016) "Risk assessment of exposure to silica dust in building demolition sites", *Safety and health at work*, Vol. 7 No.3, pp. 251-255. https://doi.org/10.1016/j.shaw.2015.12.006.

Obolewicz, J., and Dabrowski, A. (2018) "An application of the Pareto method in surveys to diagnose managers' and workers' perception of occupational safety and health on selected Polish construction sites", *International Journal of Occupational Safety and Ergonomics*, Vol. 24 No. 3, pp. 406-421. https://doi.org/10.1080/10803548.2017.1375781.

Oliver, L.C. and Miracle-Mcmahill, H. (2006) "Airway disease in highway and tunnel construction workers exposed to silica", *American Journal of Industrial Medicine*, Vol. 49 No. 12, pp. 983-996. https://doi.org/10.1002/ajim.20406.

Onder, M., Iroz, B.D. and Onder, S. (2021) "Using categorical data analyses in determination of dust-related occupational diseases in mining", *International Journal of Occupational Safety and Ergonomics*, Vol. 27 No. 1, pp. 112-120. https://doi.org/10.1080/10803548.2018.1531535.

Qi, B., and Costin, A. (2023) "BIM and Ontology-Based DfMA Framework for Prefabricated Component", *Buildings*, Vol. 13 No.2, pp. 394. https://doi.org/10.3390/buildings13020394.

Rice, F. L., Park, R. and Stayner, L., et al. (2001) "Crystalline silica exposure and lung cancer mortality in diatomaceous earth industry workers: a quantitative risk assessment", *Occupational and environmental medicine*, Vol. 58 No. 1, pp. 38-45. http://dx.doi.org/10.1136/oem.58.1.38.

Sajedian, A.A., Karimi, A. and Yarandi, M.S., *et al.* (2023) "Quantitative risk assessment of respiratory exposure to acrylonitrile vapor in petrochemical industry by US Environmental Protection Agency method: a cross-sectional study", *Medical Gas Research*, Vol. 13 No.3, p. 142. https://doi.org/10.4103/2045-9912.350859.

Schroeder, S.A. (2012) "Incidence, prevalence, and hybrid approaches to calculating disability-adjusted life years", *Population Health Metrics*, Vol. 10 No. 1, pp. 1-7. https://doi.org/10.1186/1478-7954-10-19.

Shao, T.J., Pan, L.H. and Chen, Z.Q., *et al.* (2018) "Content of Heavy Metal in the Dust of Leisure Squares

Engineering, Construction and Architectural Management

and Its Health Risk Assessment-A Case Study of Yanta District in Xi'an", *International Journal of Environmental Research and Public Health*, Vol. 15 No. 3, p. 394. https://doi.org/10.3390/ijerph15030394.

Shewiyo, B.S., Mwanga, H.H. and Mrema, E.J., *et al.* (2021) "Work-related injuries reported to workers compensation fund in Tanzania from 2016 to 2019", *International Journal of Environmental Research and Public Health*, Vol. 18 No.17, 9152. https://doi.org/10.3390/ijerph18179152.

Steenland, K., Attfield, M. and Boffetta, P., et al. (2002) "Exposure-response analysis and risk assessment for silica and silicosis mortality in a pooled analysis of six cohorts", *Occupational and environmental medicine*, Vol. 59 No.11, pp. 723-728. http://dx.doi.org/10.1136/oem.59.11.723.

Suarez, J.L., Gosselin, L. and Lehoux, N. (2023) "Optimizing Modularity of Prefabricated Residential Plumbing Systems for Construction in Remote Communities", *Journal of Construction Engineering and Management*, Vol. 149 No. 1, 05022017. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002393.

Tchiehe, D.N. and Gauthier, F. (2017) "Classification of risk acceptability and risk tolerability factors in occupational health and safety", *Safety science*, Vol. 92, pp. 138-147. https://doi.org/10.1016/j.ssci.2016.10.003

Tchiehe, D.N., and Gauthier, F. (2017) "Classification of risk acceptability and risk tolerability factors in occupational health and safety", *Safety Science*, Vol. 92, pp. 138-147. https://doi.org/10.1016/j.ssci.2016.10.003.

Tjoe Nij, E., Hilhorst, S. and Spee, T. O. N., et al. (2003) "Dust control measures in the construction industry", *Annals of Occupational Hygiene*, Vol.47 No.3, pp. 211-218. https://doi.org/10.1093/annhyg/meg023.

Tong, R., Cheng, M. and Zhang L., *et al.* (2018) "The construction dust-induced occupational health risk using Monte-Carlo simulation", *Journal of Cleaner Production*, Vol.184, pp. 598-608. https://doi.org/10.1016/j.jclepro.2018.02.286.

Trapnell, B.C., Nakata, K. and Bonella, F., *et al.* (2019) "Pulmonary alveolar proteinosis", *Nature Reviews Disease Primers*, Vol. 5 No.1, p. 16. https://doi.org/10.1038/s41572-019-0066-3.

Vested, A., Kolstad, H.A. and Basinas, I., *et al.* (2021) "Dust exposure and the impact on hospital readmission of farming and wood industry workers for asthma and chronic obstructive pulmonary disease (COPD)", *Scandinavian Journal of Work, Environment & Health*, Vol. 47 No. 2, pp.163-168. https://doi.org/10.5271/sjweh.3926.

Wang, L., Li J.Y. and Zheng, J.Z., *et al.* (2022) "Source tracing and health risk assessment of phthalate esters in household tap-water: A case study of the urban area of Quanzhou, Southeast China", *Ecotoxicology and Environmental Safety*, Vol. 248, 114277. https://doi.org/10.1016/j.ecoenv.2022.114277.

Wang, M., Yao, G. and Sun, Y., et al. (2022) "Exposure to construction dust and health impacts–A review", *Chemosphere*, 136990. https://doi.org/10.1016/j.chemosphere.2022.136990.

Xu, P., Zhu, J. and Li, H., et al. (2023) "Coupling analysis between cost and carbon emission of bamboo building materials: A perspective of supply chain", *Energy and Buildings*, Vol. 280, 112718. https://doi.org/10.1016/j.enbuild.2022.112718.

Yu, S.S., Liu, Y.F. and Wang, D.J., *et al.* (2021) "Review of thermal and environmental performance of prefabricated buildings: Implications to emission reductions in China", *Renewable and Sustainable Energy Reviews*, Vol. 137, 110472. https://doi.org/10.1016/j.rser.2020.110472.

Zhang, Y.S., Tang, W. and Li, H., *et al.* (2022) "The Evaluation of Construction Dust Diffusion and

Engineering, Construction and Architectural Management

Sedimentation Using Wind Tunnel Experiment", *Toxics*, Vol. 10 No. 8., p. 412. https://doi.org/10.3390/toxics10080412.

Zhou L.J., Cao Q.G. and Yu K., *et al.* (2018) "Research on Occupational Safety, Health Management and Risk Control Technology in Coal Mines", *International Journal of Environmental Research and Public Health*, Vol.15 No.5, p. 868. https://doi.org/10.3390/ijerph15050868.

Zhou, Y., Wang, Y. and Liu, W., *et al.* (2023) "Case report: Application of morphology in the diagnosis of siderosis in a patient with tuberculosis infection", *Frontiers in Oncology*, Vol. 13, 1001802. https://doi.org/10.3389/fonc.2023.1001802.

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Table 1. Chinese residents (adults) partially exposed parameter features.

Parameters	Unit	Distribution	Probable value	Min	Max	Mean	SD	Source
ED	a	Triangular	34	8	45	30	-	
ET	h/d	Triangular	7.5	5	8	6.83	-	Interview
AT	d	Triangular	12410	2920	16425	10950	-	
EF	d/a	Triangular	290	55	345	230	-	(Chen *et al.*,
IR	m^3/h	Triangular	1.9	0.93	2.96	1.93	-	2019)
BW	kg	Normal	-	42.1	92	69.6	5.8	

Table 2. DALY related parameters and risk factors.

Disease i	Risk factor Q	Effect factor W	Duration of risk $L_{(a)}$
Death	0.10	1	L_0 (48.2)
COPD	0.11	0.15	10
Pneumoconiosis	0.28	0.24	L_0 (48.2)
Angiocardiopathy	0.11	0.24	L_0-5 (43.2)
CVD	0.16	0.20	L_0-5 (43.2)
ARTI	0.24	0.08	0.04

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Table 3. Fitting distribution of dust concentration in different work areas.

Parameters	Unit	Distribution	Statistics data				
			Mean	SD	Skewness	Kurtosis	P-value
Ⅰ		Lognormal	0.82	0.12	0.1002	3.02	0.147
Ⅱ		Lognormal	1.51	0.15	0.1354	3.03	0.379
Ⅲ		Lognormal	3.02	0.48	0.0027	3.00	0.158
Ⅳ	mg/m^3	Normal	0.48	0.14	0.00	3.00	0.231
Ⅴ		Normal	0.25	0.10	0.00	3.00	0.215
Ⅵ		Lognormal	1.97	0.75	0.0068	3.05	0.115
Ⅶ		Lognormal	4.74	0.33	0.2593	3.12	0.493

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Table 4. Dust health risk for different work areas.

Indicator	Processing	Min	Max	Mean	SD	Percentile					
						P5	P20	P50	P75	P90	P95
R-Index ($\times 10^{-7}$)	Ⅰ	2.71	1.77	6.03	3.78	2.30	1.51	1.00	0.80	2.71	1.77
	Ⅱ	5.03	3.12	11.00	6.99	4.35	2.89	1.93	1.49	5.03	3.12
	Ⅲ	10.01	6.55	22.28	14.03	8.59	5.63	3.70	2.92	10.01	6.55
	Ⅳ	1.58	1.11	3.70	2.28	1.31	0.82	0.52	0.38	1.58	1.11
	Ⅴ	0.84	0.66	2.08	1.22	0.68	0.411	0.24	0.16	0.84	0.66
	Ⅵ	6.42	4.89	15.58	9.35	5.23	3.11	1.82	1.26	6.42	4.89
	Ⅶ	15.58	9.70	33.67	21.50	13.54	8.92	6.07	4.60	15.58	9.70

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Table 5. Damage statistics for different work areas.

Indicator	Processing	Min	Max	Mean	SD	Percentile					
						P5	P20	P50	P75	P90	P95
DALY ($\times 10^{-2}$a)	Ⅱ	0.02	13.40	1.17	0.92	2.89	1.71	0.95	0.54	0.29	0.19
	Ⅲ	0.15	40.00	4.63	3.69	11.60	6.77	3.76	2.04	1.13	0.76
	Ⅵ	0.06	28.00	3.21	2.92	8.90	4.87	2.42	1.24	0.59	0.36
	Ⅶ	0.15	57.60	6.41	4.97	15.60	9.53	5.24	2.95	1.60	1.06

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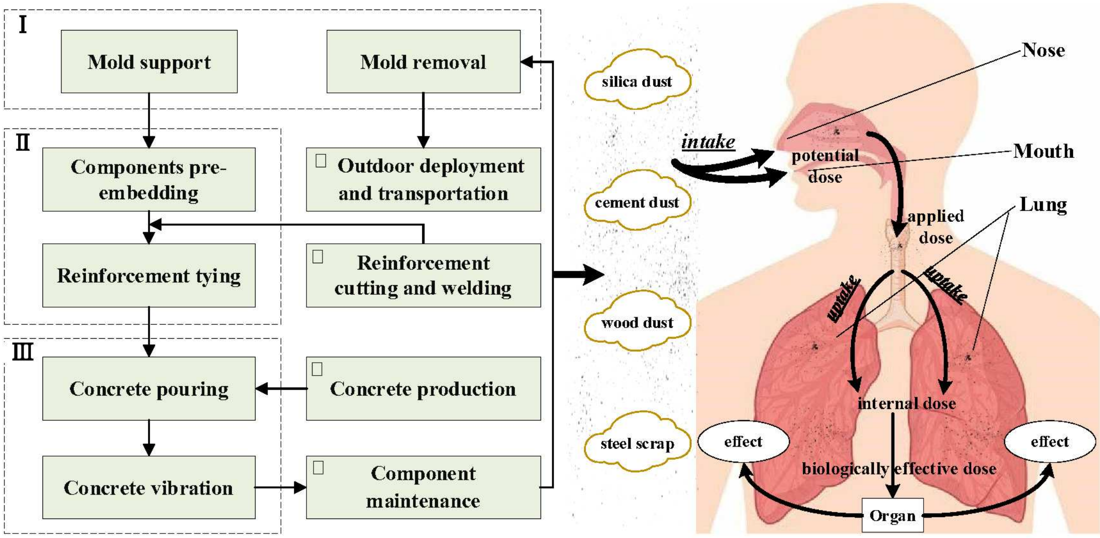

Figure 1. The production process of PCs and works' aspiratory pathway during operation.

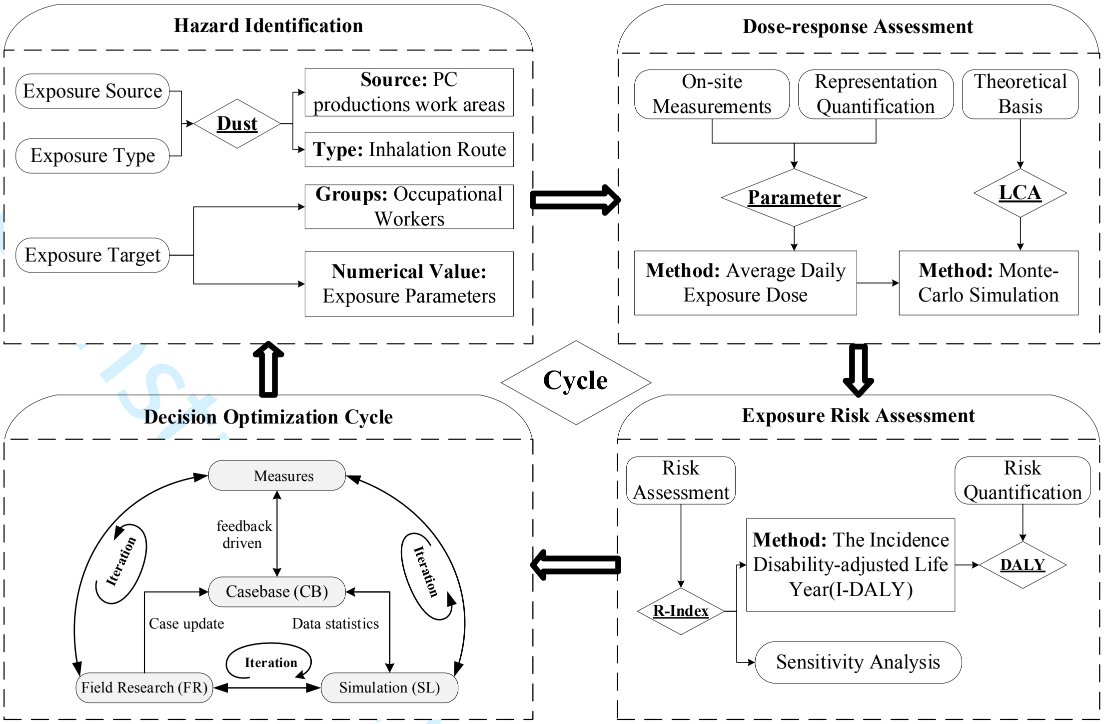

Figure 2. Damage assessment and cyclic mitigation (DACM) model.

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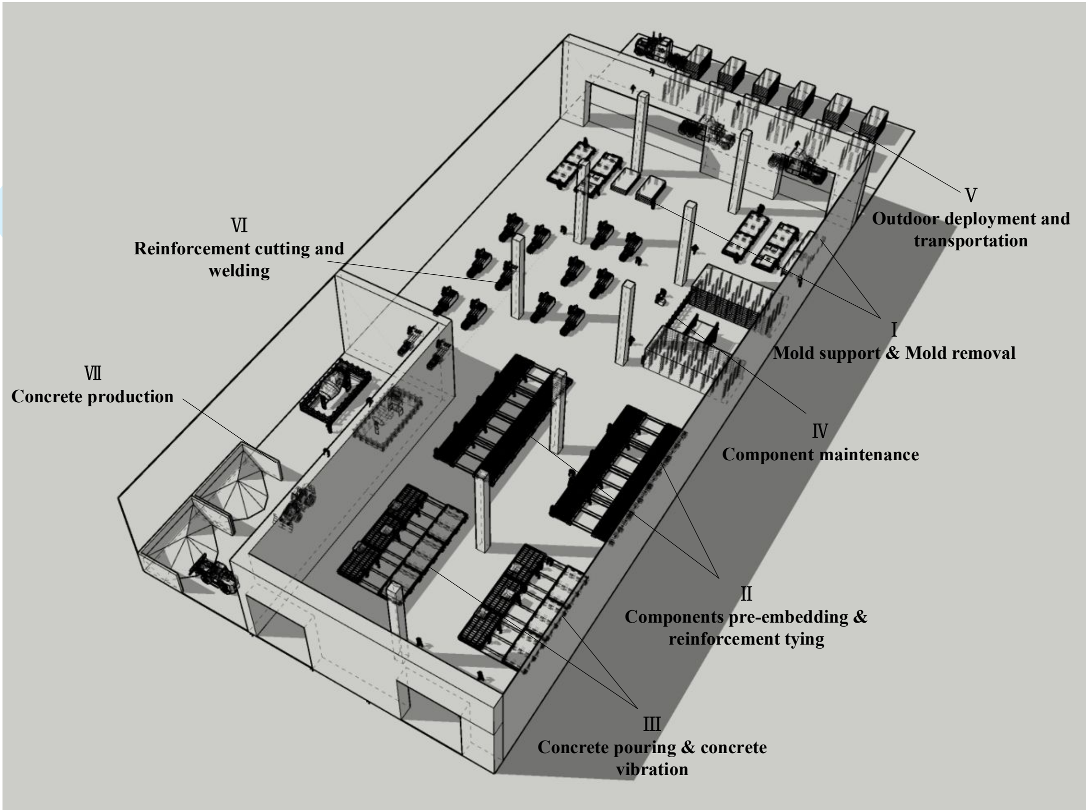

Figure 3. The distribution of a typical PC factory work area.

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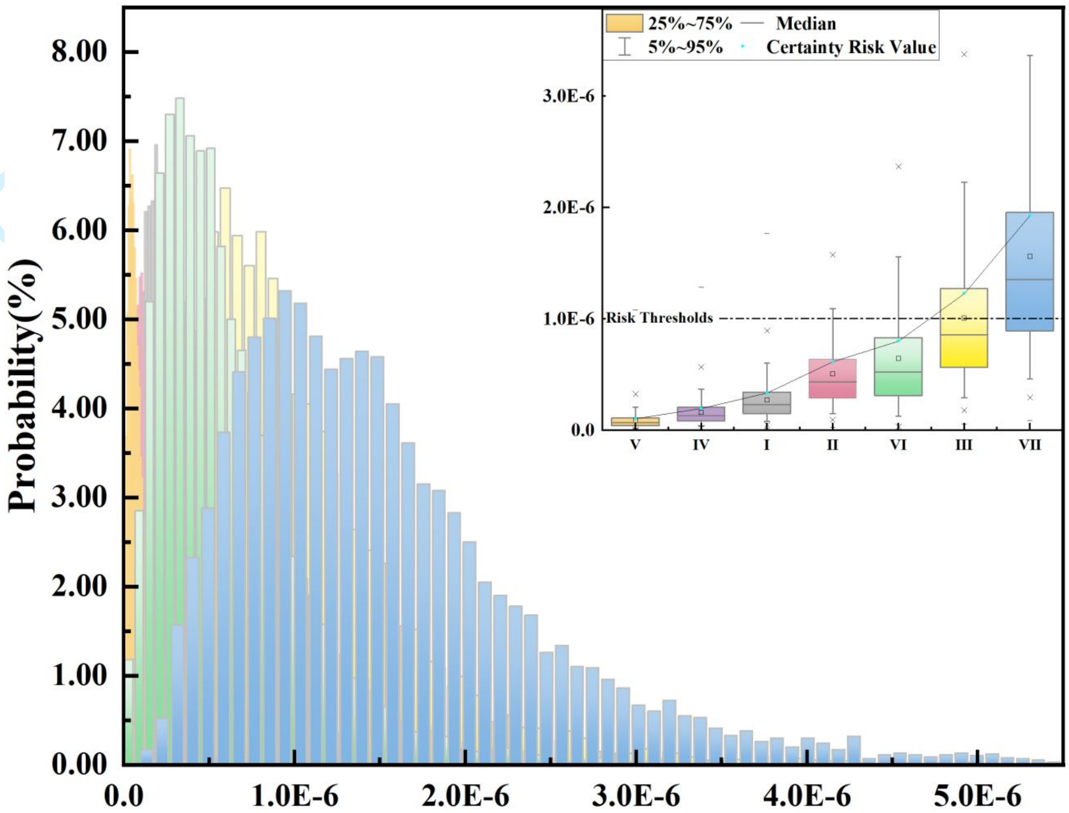

Figure 4. Simulation results of health risk caused by dust.

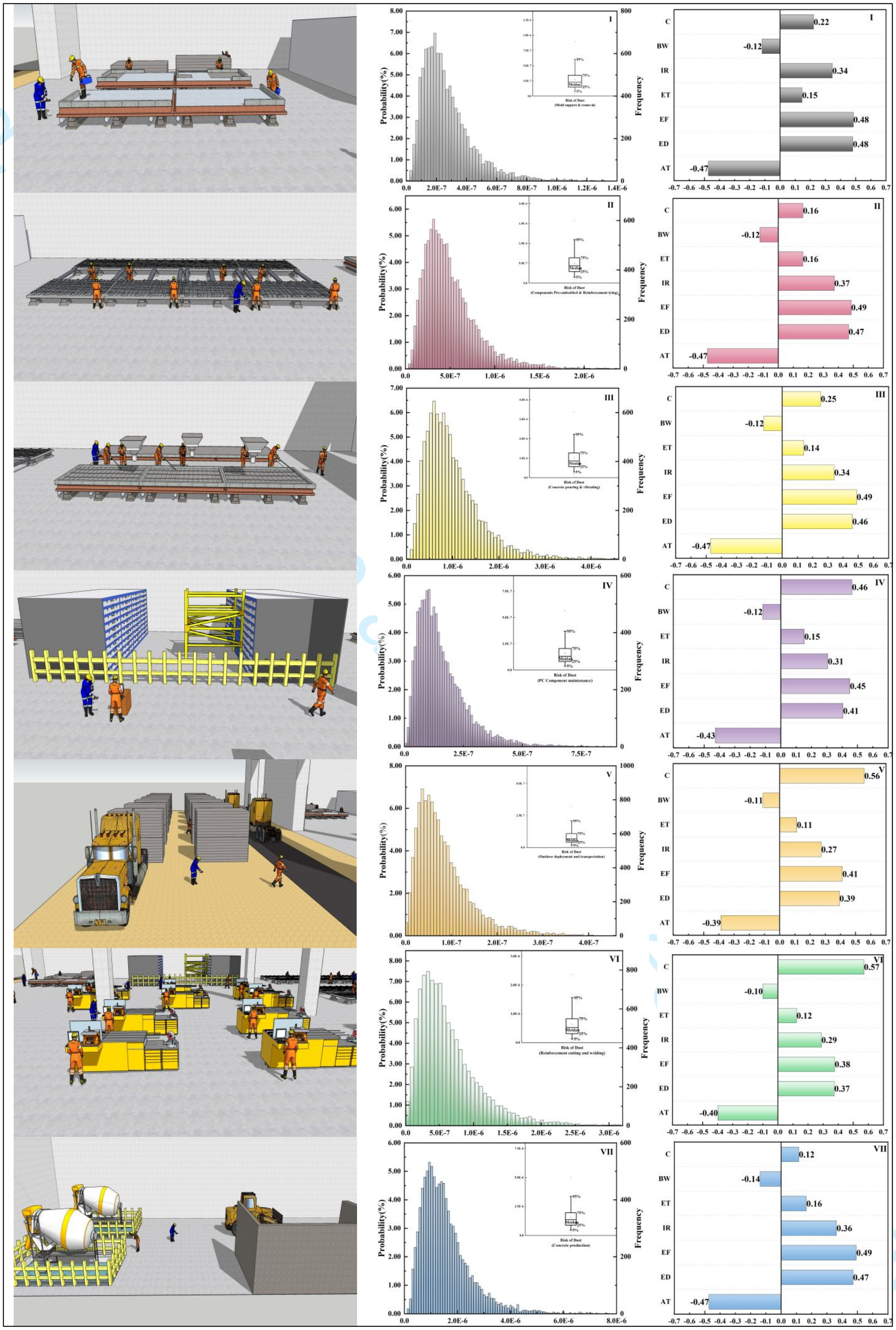

Figure 5. Results of the Risk and sensitivity analysis of the Risk parameters caused by dust in different work areas.

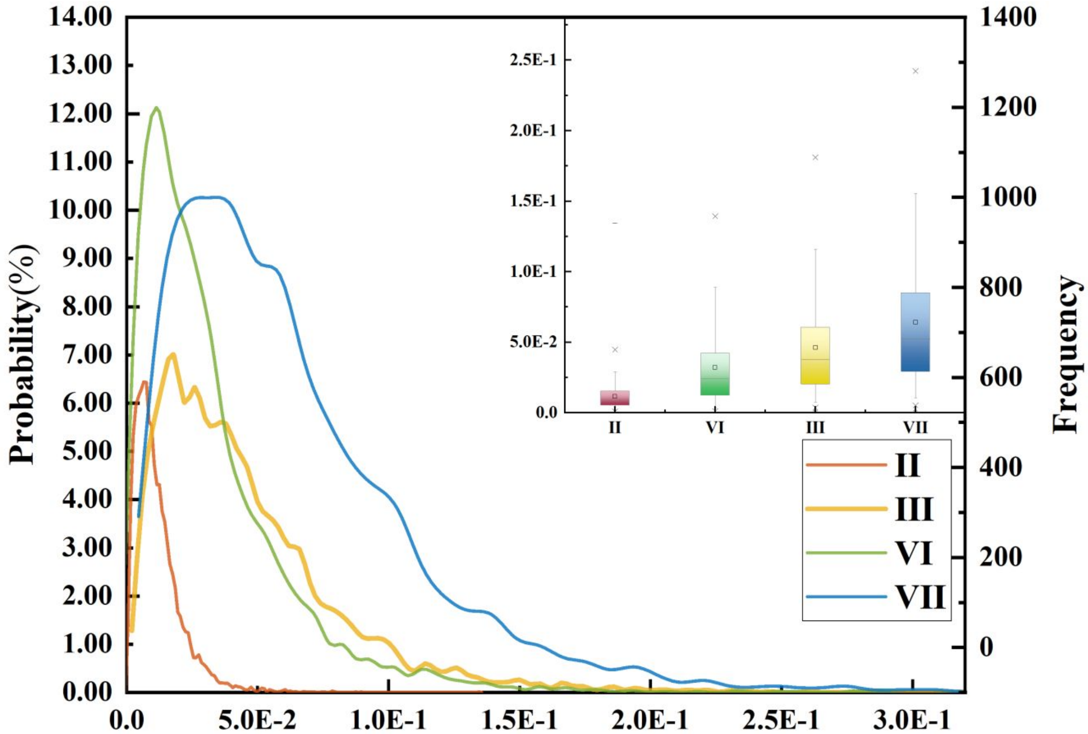

Figure 6. Results of disability-adjusted life in work areas with risk of dust exposure

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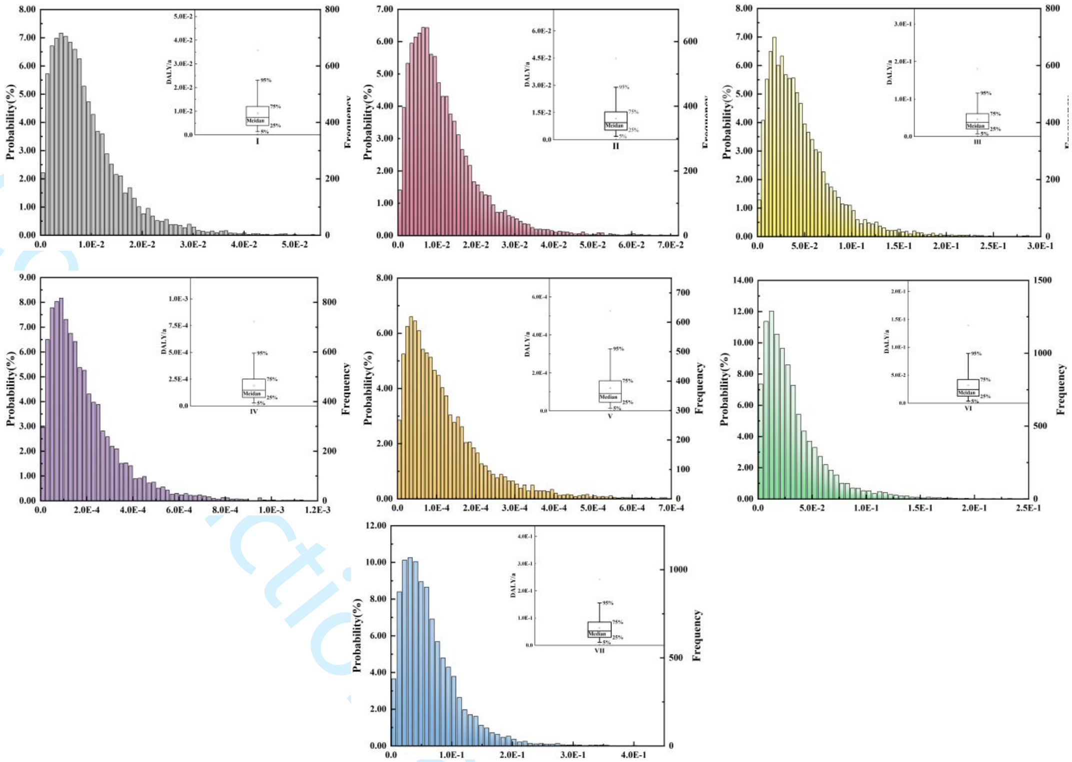

Figure 7. Results of the DALYs caused by dust in different work areas.