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RISK REDUCTION EFFECTS OF INTRODUCING AN AUTOMATED PAINTING PROCESS

Renáta Zákányi Mészáros
senior research fellow, University of Miskolc, Research Institute of Applied Earth Sciences, Chamber of Engineers of Borsod-Abaúj-Zemplén County Work Safety Group Chairman
3515 Miskolc-Egyetemváros, e-mail: zakanyine@icloud.com

Réka Ritli
student of Occupational Safety and Health Engineering, University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering,
3515 Miskolc-Egyetemváros, e-mail: reka.ritli@student.uni-miskolc.hu

Szilvia Szilágyiné Sebők
senior research fellow, University of Miskolc, Research Institute of Applied Earth Sciences, Chamber of Engineers of Borsod-Abaúj-Zemplén County Work Safety Group Chairman
3515 Miskolc-Egyetemváros, e-mail: szilvia.szilagyine@uni-miskolc.hu

Balázs Zákányi
associate professor, University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering
3515 Miskolc-Egyetemváros, e-mail: balazs.zakanyi@uni-miskolc.hu

Abstract
As a consequence of the expansion of occupations, the emergence of new businesses and new forms of occupation, the risks to workers have increased. The world of work, the modern manufacturing industry, is full of dangers and hazards in the form of accidents at work and occupational diseases (Kósa, 2001). The boom in production and the economy, combined with ever-increasing expectations of work, has led to an increase in the number of accidents at work, including occupational diseases and fatalities. Lack of knowledge of the pathogenic factors and lack of technical or personal protection are still the main reasons for the occurrence and emergence of cases of increased exposure. In the case of work with certain hazardous substances, mandatory biological monitoring is often not carried out, although early detection of cases and appropriate measures by the employer could lead to a reduction or elimination of exposure. Our work has investigated the health effects of workers exposed to chemical agents and the options for removing workers exposed to these agents from hazardous work environments. Our aim is to investigate the health effects of chemical agents on humans and the possibilities of their induction in order to reduce or provide optimal conditions for safe and healthy working. During the study, particular attention was paid to the investigation of substitutes and the possibility of automation (Páva and Gábor, 2002).

Keywords: *occupational safety, human safety, chemical hazard, robotic technology*

1. Introduction

Chemicals are everywhere in people's lives. The number of registered chemicals and mixtures is in the tens of millions, of which at least 130,000 are commercially available, 10% of which are classified as extremely hazardous. This number is truly staggering in the light of the World Health Organisation's statement that 'each substance is a potential risk factor' (Ungvári, 2000), as it can be the cause of a number of human diseases and thus occupational diseases. The rapid proliferation of chemicals is associated with many dangers, which requires the full implementation of chemical safety, taking into account, of course, sustainable development. Harm from hazardous substances can occur as a result of a single brief exposure, long-term exposure or long-term accumulation of substances in the body.

The task of occupational safety and health is therefore to promote and maintain the highest level of physical, mental and social well-being of workers in all occupations, to prevent damage to workers' health arising from working conditions, to protect workers from risks to their health, and to provide and maintain a working environment adapted to the physiological capabilities of workers.

The chemical industry is producing large quantities of substances that are harmful to both health and the environment to meet growing industrial demands. The production, storage, transport and, not least, use of these substances are not without risk, even under the strictest safety standards. Recognising this, developed countries are developing new guidelines to reduce the level of risk, which is increasing in line with the pace of chemicalisation. In the field of occupational safety and health, EU legislation is characterised by two main trends. On the one hand, the so-called "New Approach", introduced to ensure the free movement and safety of industrial products, is dominant. This means that products manufactured in compliance with the requirements of the relevant directives can be freely marketed in the Member States. This currently includes personal protective equipment. On the other hand, the legislation on occupational safety and health lays down a set of requirements for specific sectors. The specificity of this is that the provisions of the directives thus developed are set out as minimum essential requirements, against which the state may tighten, but never relax, in accordance with national practice (Páva and Gábor, 2002; Keisz, 2010).

2. Demonstration of the painting process used

The painting process starts with the mixing of the paint materials. Before mixing, the expiry date of the dyes and the suitability of the components are checked. After the check, the base components are mixed in a mixing machine located in the paint mixing room, where the paint is mixed by the machine for 1 minute. After the base component is properly homogenised, the paint is poured into a clean container and the hardener is added. The hardener is added slowly and continuously to the base component until the compound is completely homogeneous. Dilution is then carried out with distilled water. The distilled water is added to the compound in two steps and the viscosity of the resulting compound is measured. As a final step in the process, the dye is filtered and assigned a mixing number. The resulting paint is poured into the paint container of a spray gun designed for this painting process. The parts to be painted are then pushed into the painting chamber using a roller stand and painting is carried out here using a compressed air spray gun. The amount of paint applied to the parts depends on the type of parts. Once painting is complete, the parts are dried in the paint booth. The drying time depends on the size of the parts and the thickness of the paint applied.

Figure 1. *Applied painting process*

3. Summary of recommendations and conclusions for safe operation

Robotic automated coating has long been considered state-of-the-art technology in the automotive industry. More and more companies are seeing the need to automate painting with robots, which not only reduces the number of defects, but also the number of people working in dangerous environments. The company we studied aims to combine high quality robotic painting with a flexible and cost-effective solution, and to reduce the number of workers exposed to harmful chemicals in hazardous jobs.

Paint equipment and robot manufacturers offer multi-axis robots specifically designed for industrial coating applications, for the application of solvent- or water-based, single- and multi-component paints, with the technology adapted to the customer's specific project. The new spray gun controllers provided for the technology allow very precise application. All painting parameters are easily accessible and can be adjusted with extreme precision, resulting in high repeatability and uniform coating. There are several programs that allow manual training of the robot's motion sequence. With the appropriate software tools, the correct motion sequence and spreading path can be programmed for each workpiece on the PC workstation. However, this does not mean that coating specialists are not needed to determine the ideal painting sequence. Automation is not limited to movement sequences and painting. It can include paint preparation, paint movement and dispensing, and colour change. For all these, new improvements are available for automated processes, contributing to optimised quality and efficient use of resources. The integration of systems for automated monitoring of process parameters such as paint volumes, temperature, air supply and nozzles, and the logging and evaluation of this data is becoming increasingly important for coating companies. Quality control solutions for coated surfaces can also be integrated into the process.

4. Risk assessment and evaluation

The risks arising from the painting process in the company's factory constitute a danger for both the workers and the persons in the vicinity of the work, and the detailed assessment required by the law is therefore absolutely justified. The aim of the risk assessment is to identify the sources of danger arising from the technology which could pose a risk of health hazards to the operator. The starting point, in addition to legal compliance, is an assessment of the chemicals and substitutes used in the painting process, as well as an evaluation of the risks arising from possible automation, which can serve as a basis for the development of a coherent and comprehensive prevention strategy for the company and for the adoption of corrective measures. The risk assessment was based on the collection of information, including observation and verbal briefings, careful study of safety data sheets and the machine manuals and instructions for use of possible painting robots. The process of information gathering covered the hazardous substances and substitutes used in the manufacturing process, taking into account their life cycle in the workplace, the workplace, the work process and its immediate environment, and the risks of the painting robot.

It is absolutely necessary to carry out a risk assessment:

- identify the threat;
- analysis of the exposure-effect (concentration/dose-effect) relationship;
- the exposure assessment
- qualitative and quantitative characterisation of the risk.

Identifying hazards is the basis for risk assessment, so the first step is to take account of all work processes and technologies in the work environment, with particular attention to hazardous substances and preparations. Hazards can arise from a number of factors, therefore all relevant factors for which the employer is responsible have been considered in the risk assessment. To this end, the identification of hazards was based on direct observation of work activities, work processes, technologies, work equipment, work methods, manufacturers' and suppliers' instructions, data sheets, machine manuals, operating instructions and workers' experience during the site visit. In the company inspected, parts are painted in painting booths designed for this purpose. The painting processes involve the use of surface treatment agents, sealants and paints containing significant quantities of organic solvents, some of which are classified as carcinogenic.

Perhaps the most intrinsic stage of risk characterisation is the dose-response analysis, which deals with the extent to which the amount of chemical agent exposed to the body causes damage or disease in the living organism. Human toxicological data on health effects from chemical exposure are relatively limited, so this stage of the risk assessment involves comparing doses that have been shown to be toxic in experimental animals with the amount of substance that is present in humans during exposure. The formation, collection and use of animal data is based on the assumption that conclusions can be drawn from the toxicological results of the animals involved in the experiments for humans. For example, all chemicals that cause cancer in humans have been shown in animal studies to be carcinogenic in all or several species. There is also a high degree of similarity with regard to acute poisoning. The different types of toxicological studies differ in the methods used, but are aimed at

- identify which organs and organ systems are damaged by a given substance,
- to detect structural, morphological or molecular changes and functional disturbances in the structure, cells and cellular components of the organism,
- to determine the exposure conditions and doses that cause abnormality, damage, disease, mortality,
- understand the nature of the damage and the biological process leading to the damage,
- and ultimately serve the purpose of determining the no- or minimally harmful levels of a given chemical (Ádám et al., 1993; Váró et al., 2012; Bullock and Ignacio, 1998).

Toxic effects are generally classified according to the organ/organ system affected, distinguishing between substances/effects that damage the liver, kidneys, reproductive system, respiratory system, central and peripheral nervous system, immune system, eyes, skin, haematopoiesis, cardiovascular system, and genotoxic substances that damage the genome of cells and can lead to mutation and tumour formation.

By toxicological specificity:

- Toxic hazardous substances and mixtures;
- Harmful hazardous substances and mixtures;
- Corrosive hazardous substances and mixtures;
- Irritant hazardous substances and mixtures;

- Sensitising dangerous substances and mixtures.

Table 1. *Classification of chemicals by carcinogenicity*

1 class	proven human carcinogens (carcinogens that cause cancer),
Class 2A	probably human carcinogens, human evidence is limited, animal evidence is sufficient,
Class 2B	possible human carcinogens, limited human evidence available but insufficient animal evidence; no human data, sufficient animal evidence; occasionally substances for which there is no human data and limited animal evidence are included,
3 class	the substance is not classified as a human carcinogen,
Class 4	the substance is probably not carcinogenic to humans.

In terms of toxicity, exposure to solvent vapours in the materials used for painting may cause adverse health effects exceeding the given occupational exposure limit. The substances tested may be carcinogenic and therefore the toxicological assessment should take into account the adverse health effects of this. The company is exposed to occupational exposure to chromium in the manufacture of components, with acute and chronic effects on workers. Exposure to solvent vapours at concentrations above the occupational exposure limit values may result in adverse health effects.

The test substances cause irritation to the mucous membranes and respiratory system, and have significant effects on the kidney, liver and central nervous system, so contact with the substances, contact with the eyes and inhalation of their vapours should be avoided.

Planned introduction of automated technology to reduce the number of workers exposed to chemicals.

Figure 2. *Evolution of the number of workers exposed*

Using a robot can reduce the number of workers exposed to chemical risks by 17%. This means that with one robot we can take 3 people out of the hazardous working environment, which is not a lot in terms of numbers, but considering that we have not exposed one person to the harmful effects of chemicals, it is significant.

5. Results of the risk assessment for hazardous substances

No occupational diseases or accidents have been reported as a result of the use of hazardous substances and mixtures, but the continuous and large-scale use of hazardous substances and mixtures justifies the need for an exposure air pollution study.

A biological monitoring study is required, as a biological exposure indicator is established for hazardous substances and mixtures on the basis of the safety data sheet. The technology of the activities carried out by the company justifies the use of the substances, and therefore workers carrying out the painting operations are exposed to the carcinogenic effects of the substances used. In order to prevent occupational diseases caused by chromium, it is necessary to define, in collaboration with the occupational health service, the workers who should not be employed in this type of work.

Such persons are:

- people with known chromium allergies (asthma or skin symptoms) and atopic people should also be considered as they are at higher risk,
- people with chronic inflammation of the upper airways,
- people with chronic skin conditions,
- Women under 18 years of age, pregnant, breastfeeding, breast milk feeding.

During the pre-employment assessment, it is particularly important that additional tests are carried out in addition to the general internal examinations.

- respiratory function,
- ear, nose and throat,
- dermatology (including a skin test if chromium allergy is raised during the history taking),
- laboratory tests (blood count, urine, liver enzymes),
- chest X-ray.

Periodic aptitude tests are required annually, with a final test at the end of employment with carcinogenic chromium compounds. The substances used in the painting process are harmful irritants which may cause damage to health if inhaled or absorbed through the skin. The substances may cause inflammation in the case of momentary or prolonged repeated contact with the skin, eyes or mucous membranes. The employer provides personal protective equipment for the work process. However, the risks arising from the strain caused by personal protective equipment must be taken into account, since the worker must wear several protective devices at the same time in order to ensure effective protection, which places an additional burden on the person carrying out the work. Due to the inconvenience, workers often do not use the required and prescribed personal protective equipment for painting operations, but this exposes them to increased risk and increases the risk of occupational disease.

Given the long intervals of estimated daily exposure time, it is imperative that risk mitigation measures are taken in view of the above.

Possible means of prevention:

- reducing the concentration of chromium in the workplace air through technical solutions;

- environmental monitoring – regular measurement of chromium concentrations in the air of the workplace, compliance with the occupational limits set by the regulations in force at any given time;
- personal protective equipment: appropriate skin protection, respiratory protection;
- observing personal hygiene rules (washing hands, eating, not smoking in the workplace, cleaning up after work, proper handling of soiled protective clothing);
- biological monitoring: measurement of urinary chromium concentrations, compliance with the occupational exposure limit values set by the Regulation, and in case of exceedance – "increased exposure" – taking appropriate measures to reduce exposure.

6. Summary

Automation has long been central to industry. Technological advances in recent years have created alternative possibilities for industrial automation that make it essential for the competitiveness of modern factories to employ some level of automation. There are a number of reasons for the adoption and wider spread of automation, which offer a number of advantages for firms that prefer automation. Automated and digitalised processes and efficient product customisation solutions are among the key trends in industrial painting technology (Perkins, 2008; Cherrie et al., 2010; French et al., 2017). New developments will allow to efficiently meet increasing quality, material and energy efficiency demands. Coating companies with paint shops are facing changing and new demands that require increasing attention to sustainability, economic efficiency, worker health and the global shortage of skilled labour.

The use of industrial robots in the painting process of parts has many advantages, not only for the health of the workers, but also for the economy of the company under study. When comparing the painting process by robot and by man, it is easy to see that there are many arguments in favour of automation. Robots are able to work continuously with shorter cycle times without the loss of concentration that is typical of human work. The use of industrial robots increases the speed of the manufacturing process as robots do not need to take breaks, so the speed and reliability of robots reduces cycle times and maximises production capacity. Another major advantage is the cost-effective use of materials.

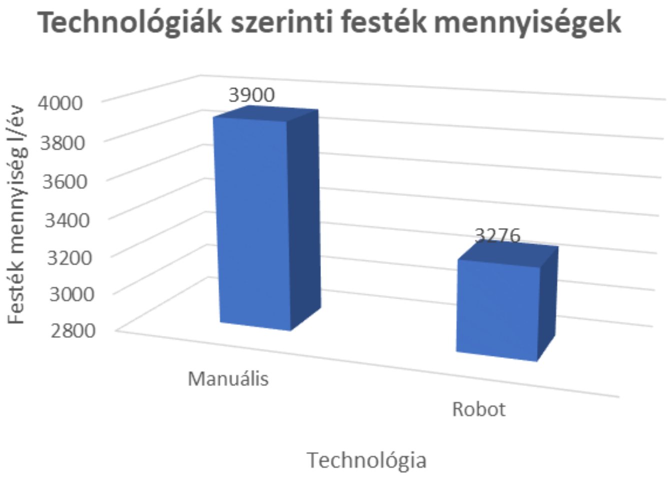

Figure 3. *Trends in the use of chemicals*

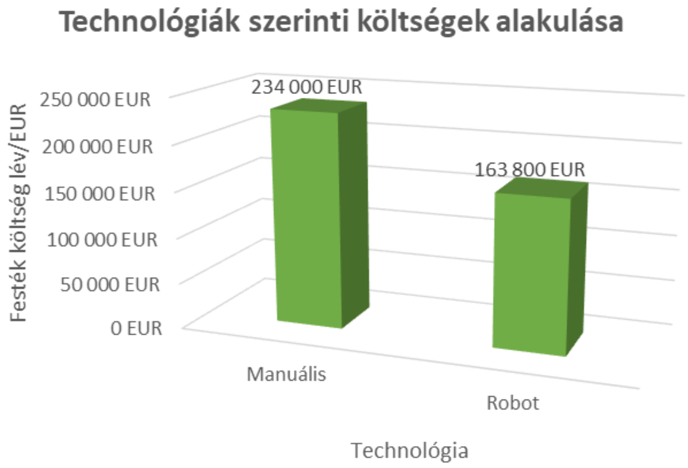

Figure 4. *Chemical cost evolution*

The diagram shows that the amount of chemicals used in the painting process in our company can be reduced by up to 20% just by using a robot, which results in significant cost savings. Of course, to assess the time to return on the capital invested in automation requires a high-level costing exercise, which we have not sought to address in our work. Another major benefit of automation is that it can also increase safety in the workplace, since the use of industrial robots with repetitive tasks poses less health risk to workers, especially when production has to be carried out in conditions hazardous to humans with toxic chemicals. On the other hand, painting processes can be monitored from a remote location. The use of industrial robots can also reduce direct labour costs, as the use of human labour in the painting process is more expensive as it requires appropriate skills and is nowadays considered a shortage occupation. The use of human labour also brings other additional costs, such as illnesses, which can lead to lost working days and thus reduce production.

Automation can also help to free up human labour, as workers and thus their skills and expertise can be used in other areas of production, such as the proper preparation of products for the painting process. Many workers are against the idea of automation, believing that robots will take jobs away from workers, but this is not necessarily true. Industrial robots are generally set up for monotonous operations, and performing tasks that require intuitive thinking definitely requires human labour. Supervising, programming, operating and maintaining the operation of robots requires new jobs, which in turn require a high level of expertise on the part of workers.

Today, the number of professionals with these skills is currently limited, so it is of paramount importance for the company under review to consider investing in the skills of the staff it already has if it wishes to engage its current staff to carry out these tasks in the future. Of course, the use of industrial robots has not only advantages but also disadvantages. The use of robots requires a substantial initial investment, and all the costs (installation, operation, maintenance) must be taken into account when drawing up the investment plan. The flexibility of the automated operation should be assessed before purchasing, in case the operation needs to be changed in the future. While industrial robots can reduce some labour costs, they also generate new costs, such as re-programming and maintenance costs.

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