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Identification and analysis of advanced manufacturing processes susceptible of generating new and emerging occupational risks

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Abstract

Advanced manufacturing processes (AMP) are characterized by innovative variables of a technological and organizational nature which tend to change with workplaces, processes and conventional work practices, and can generate, as well as traditional occupational risks, other so-called new and emerging risks (NER). The main innovative aspect of this paper is that such risks have been analyzed applying recent specific models in the field, with the overall aim of identifying susceptible AMP of generating NER. From the results the main apparent conclusion is that there is NER of a general nature susceptible in AMP but it is not possible, in most cases, to establish direct links with specific AMP. However, it has been possible to identify among those NER a set of technological aspects with which can be established a starting point to facilitate the identification of AMP that are potential generators of NER.

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Keywords: advanced process; manufacturing; new and emerging risk; occupational risk; risk model;

1. Introduction

The advanced manufacturing process (AMP), due to its innovative characteristics, are susceptible to generating, as well as traditional occupational risks, others defined by the European Agency for Safety and Health at Work (EU-OSHA) as new and emerging risks (NER), being its basic definition "any occupational risk that is both new and

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increasing" with that Agency taking the first steps in identifying specific NER with the publication of four reports, that make up the framework of this study, covering physical risks [1], biological [2], psychosocial [3] and chemical [4].

The International Labour Organization [5] indicates the need for research in the field of NER, looking at alternatives when they are the result of new technologies, work processes or substances. In this context, in the prospective study on NER associated with new technologies in 2020, published by the EU-OSHA [6], were selected from the eight new technologies that could help create NER in green jobs by 2020.

In recent research published by Brocal and Sebastian [7] a model of NER has been developed that enhances and complements the concept of NER defined by the EU-OSHA, from which a decomposition model has been designed following the methodology proposed by Brocal [8] that allows as the main innovative aspect, analysis of the considered structured set of NER, with which, results have been obtained consistent with the general procedures for evaluating occupational risks applied to AMP.

2. Goals

The general objective is the identification and analysis of susceptible AMP to generate NER. From this general objective the following specific objectives are derived: (a) To identify NER directly linked to specific AMP and (b) To identify the main technological and biological aspects of NER linked to AMP.

3. Methodology

For the development of this paper the following methodology is structured in two phases, as shown in Figure 1:

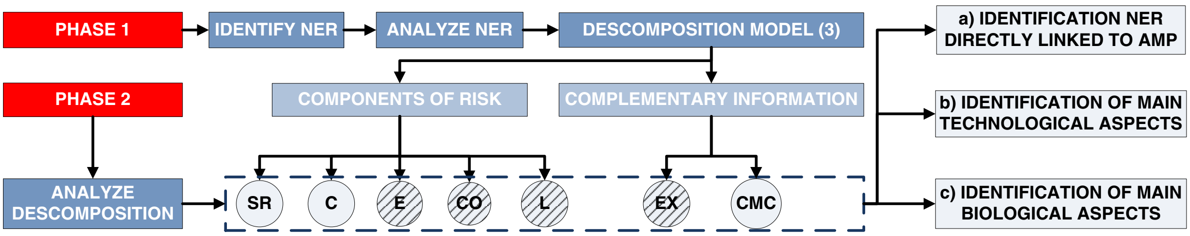

Figure 1. Methodology

- Phase 1: Identify and decompose NER associated with AMP: in studies of the EU-OSHA [1-4], the NER will be identified following the criteria of Brocal [9] and subsequently these will be decomposed applying the decomposition model, proposed by Brocal and Sebastián [7].
- Phase 2: Analyze the results of the decomposition obtained in phase 1 seeking compliance with the particular objectives. This is carried out as follows:

  a) Identification of NER directly linked to specific AMP: these NER must contain in their description, direct and specific information from their area of application in relation to the specific technological features of one or more AMP. For this, NER components that have been analyzed are: source of risk, cause, and characteristic manufacturing context (SR, C and CMC). The other components (E, CO and L), were not analyzed because they do not contribute relevant information to the objectives. In the specific case of the examples, component (EX) was neither analyzed because by itself it does not fit the criteria stated above, because as an example it does not represent the scope of NER. With regards to the specific set of AMP, those considered by Groover [10], will be used as reference-non exhaustive- during this study.

  b) Identification of the main technological aspects of NER linked to AMP: characteristics will be identified among the NER that do not meet the above conditions, by analyzing the same components (SR, C and CMC). For technological aspects it is understood that those technical characteristic, material and organizational, provided by the components indicated without being specific to AMP, can be considered elements of general application in the field of AMP. Therefore, the criteria to be followed is as follows, based on the nature of the information that generally accompanies the complete descriptions of the NER:

1. Technological aspects of a technical character: will be identified between physical NER;
2. Technological aspects of a material character: will be identified between chemical NER;
3. Technological aspects of an organizational character: will be identified by analyzing only the cause component (C) among the four groups of NER (physical, chemical, biological and psychosocial). In this way, when a certain number of cases can be grouped, based on the criteria of adapting NER proposed by Brocal [8], they will be collected as a whole and not as a unit.

c) Identification of the main biological aspects linked to AMP: identification between biological NER, being those contaminants that due to their characteristics are likely to be present in various AMP, both by direct causes (such as cutting fluids) and indirect (for example air conditioning system) associated with the processes themselves.

4. Identification and analysis of NER applicable to AMP

This section is developed following the scheme outlined in the methodology. For this and as a first step, the concept of NER is defined according to EU-OSHA. Complementarily different risk models necessary for the development of this work are also defined.

4.1. Definitions

Definition 1. NER: any occupational risk that is both new and increasing [1-4]:

- The risk is «new» if:
  - C1. the risk did not previously exist and is caused by new processes, new technologies, new types of workplace, or social or organizational change; or,
  - C2. a long-standing issue is newly considered as a risk due to a change in social or public perceptions; or,
  - C3. new scientific knowledge allows a long-standing issue to be identified as a risk.
- The risk is «increasing» if:
  - C4. number of hazards leading to the risk is growing; or
  - C5. the exposure to the hazard leading to the risk is increasing (exposure level and/or the number of people exposed); or
  - C6. the effect of the hazard on workers' health is getting worse (seriousness of health effects and/or the number of people affected).

Unlike the original sources cited, the codification (Ci) in this paper is the "condition" that defines an NER [7].

Definition 2. Risk model (R): a risk (R) is a structure consisting of five components, being: the source of risk (SR), causes (C), events (E), consequences (CO) and the likelihood (L); this set may be expressed as (1) [7].

$$\mathrm{R} = (\mathrm{SR}, \mathrm{C}, \mathrm{E}, \mathrm{CO}, \mathrm{L}) \quad (1)$$

Definition 3. NER model: a particular occupational risk (R) belongs to the set of NER if and only if its components configure at least one ordered pair (r, c) belongs to the subset of conditions which may define a new risk (N) and at least one ordered pair (r, c) on the subset of conditions that can define an increasing risk (I), which can be expressed as (2) [7].

$$\mathrm{R} \in \mathrm{NER\ iff} \ \exists\ (\mathrm{r}, \mathrm{c}) \in \mathrm{N\ and} \ \exists\ (\mathrm{r}, \mathrm{c}) \quad (2)$$

Definition 4. Decomposition model: the complete description of all identified NER can be decomposed into two sets of variables: (i) components according to the Risk model (1); (ii) complementary information (CI) which at the same time is formed of: examples (EX) and characteristic manufacturing context (CMC) may be expressed as (3). Thus, all information contained in the complete description of all NER, will be assigned to any of these variables (variables can be unassigned) [7].

$$\mathrm{Descomposed\ NER} = (\mathrm{R}, \mathrm{CI}) \quad (3)$$

4.2. Phase 1: Identification of NER applicable to AMP

The methodology used in the reference studies of EU-OSHA to identify NER [7, 8, 9, 10], was based on the Delphi method, using for classification of such risks the Likert five-point scale. From the results obtained, in the present work, following the principle of Brocal [9] only the NER classified as "risk strongly agreed as emerging" and "risk agreed as emerging" have been considered as in other cases ("undecided"; "a risk agreed as non-emerging"; "risk strongly agreed as non-emerging") can be considered that the risks identified are not NER. Reference will be made hereinafter to such risks as "NER identified" and their original names as "complete description".

After identifying NER, following the criteria above, they have been decomposed according to the decomposition model (4). In the Table 1 is shows an example [7] of the complete description of a NER chemical group, which has been decomposed in the format shown. Thus, all information contained in the complete description of all NER, will be assigned to any of these variables (variables can be unassigned).

Table 1. Example 1 of a decomposed NER [7]

NER (Complete description)	COMPONENTS OF RISK						COMPLEMENTARY INFORMATION
	SR	C	E	CO	L	EX	CMC
Semi-conductor industry: exposure to metal fumes and dust leading to skin sensitization and respiratory diseases [10]	Metal fumes and dust	---	---	Skin sensitization and respiratory diseases	---	---	Semi-conductor industry

4.3. Phase 2: Analysis of the results of the decomposition obtained in phase 1

With this phase, in first place, the NER directly linked to specific AMP will be identified, and then, technological and biological aspects will be identified of the NER linked to AMP.

4.3.1. Identification of NER directly linked to specific AMP

NER selected have been those whose components (SR, CO and CMC) that fit the criteria outlined in the methodology section. In example 1, a NER is shown, where a CMC component is deducted in a direct way through its association with the manufacturing processes related to semiconductors (processes that could be included in the "special processing technologies and assembly" considered by Groover [10]). In Table 2, a second example is shown, where a direct link of the NER with laser machining processes is deducted through the component SR.

Table 2. Example 2: Identification of NER directly linked to specific AMP

NER (Complete description)	COMPONENTS OF RISK					COMPLEMENTARY INFORMATION	
	SR	C	E	CO	L	EX	CMC
Physical material treatment (laser applications) creating nanoparticles [1]	Laser application creating nanoparticles	---	---	---	---	---	---

4.3.2. Identification of the main technological and biological aspects of NER linked to AMP

In this section, keeping the criterion of considering those characteristics of the components that can set a specific NER, the NER that have been selected are those where one or more of the components (SR, C and CMC) can be related in a direct way with (technical and organizational) technological aspects own of AMP.

In Table 3, an example of a NER is shown, where through the SR component, is deducted in a direct way the technological aspect of technical character called "human-machine interface". In Table 4, it can be seen another example where in this case the technological aspect is a material such as the "crystalline silica". In both cases, the identified technological aspects can be found in a wide range of AMP, therefore they have not associated with specific AMP, not because it is not possible, but because such relations are outside the scope of this paper.

Table 3. Example 3: identification of a technical aspect

NER (Complete description)	COMPONENTS OF RISK					COMPLEMENTARY INFORMATION	
	SR	C	E	CO	L	EX	CMC
Poor ergonomic design of human-machine interfaces (complexity of human-machine-interface; high forces required to operate machinery) [1]	Human-machine-interface (HMI)	Poor ergonomic design (complexity HMI; high forces required to operate machinery)	---	---	---	---	---

Table 4. Example 4: identification of a material aspect

NER (Complete description)	COMPONENTS OF RISK					COMPLEMENTARY INFORMATION	
	SR	C	E	CO	L	EX	CMC
Crystalline silica [4]	Crystalline silica	---	---	---	---	---	---

Regarding the organizational aspects, in Table 5 an example of NER is shown, where can be seen that the cause (C) of the risk is closely related to work organization. Similarly as in the previous examples, this organizational aspect may be considered, potentially, of general application to AMP.

Table 5. Example 5: identification of an organizational aspect

NER (Complete description)	COMPONENTS OF RISK					COMPLEMENTARY INFORMATION	
	SR	C	E	CO	L	EX	CMC
Longer working hours at VDU workplaces leading to fatigue and exhaustion [1]	VDU workplaces	Longer working hours	---	Fatigue and exhaustion	---	---	---

Among biological NER, the criteria for to identify the respective aspects have been established independently from the technological aspects, precisely because of their special characteristics of biological type. For this, the biological contaminant has been selected when possible as the most representative indicator of NER in the general context of the AMP, such as the endotoxins according to shown in Example 6 of Table 6.

Table 6. Example 6: identification of a biological aspect

NER (Complete description)	COMPONENTS OF RISK					COMPLEMENTARY INFORMATION	
	SR	C	E	CO	L	EX	CMC
Endotoxins: High concentrations in various industrial settings (e.g. in workplaces exposed to organic materials (straw, wood, cotton dust), waste treatment, poultry houses, swine confinement buildings) leading to asthma, loss of lung function, etc.[2]	Endo-toxins	---	High concentrations	Asthma, loss of lung function, etc.	---	Industrial settings exposed to organic materials (straw, wood, cotton dust), waste treatment, poultry houses, swine confinement buildings)	---

5. Results

In this section, the results are shown according to the two phases described in the methodology.

5.1. Phase 1: Identification of NER applicable to AMP

Applying the criteria of Brocal [9], 171 NER has been identified compatible with AMP, distributed in groups with the following absolute frequencies [7]: 58 physical; 19 biological; 27 psychosocial and 67 chemical. This set of

NER has been decomposed individually according to the decomposition model (3), taking from the results a descriptive statistical analysis, the following showing the most relevant results summarized. This analysis has been performed on dichotomous variables of a qualitative nature, depending on if the component (CT) risk has been identified (true) or not identified (false) in each decomposed NER, using the following code: true = CT ; false = $\overline{CT}$. For the purposes of the analysis of the frequencies associated with CT variable, seven risk components that configure the NER itself (SR, C, E, CO, L, EX and CMC) are of interest, for which their first order frequencies have been studied (for the four risk groups) counting each (true) component individually identified, obtaining the following absolute frequencies as shown in Figure 2: SR=127; C= 84; E = 60; CO= 57; CMC= 48; L= 40; EX=22.

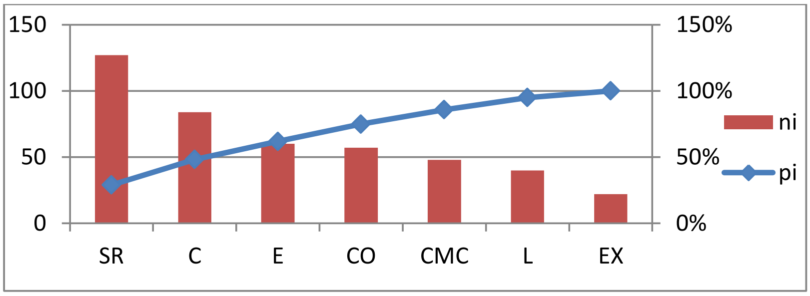

Fig. 2. Pareto Charts (ni: absolute frequency, Pi: cumulative percentage) of the distribution of NER components (for the four groups) according to first order frequencies

5.2. Phase 2: Analysis of the results of the decomposition obtained in phase 1

Through Tables 7, 8 and 9, the results obtained after analysis of the first phase are shown.

Table 7. Identification of NER directly linked to specific AMP

NER (Complete description)	AMP	COMP. OF RISK
NER PHYSICAL [1]		
General increase of exposure to UV radiation (during leisure time; occupational outdoor activities; new UV technologies at the workplace) increasing the sensitivity to UV radiation at the workplace	Photolithography; Micromanufacturing: photofabrication	SR
New laser technologies and light emitting diodes (LEDs) in communication engineering (optic rays for data transfer)	Laser beam machining; Micro-soldering; Metal heat treatments; Measurement	SR
Laser applications creating chemical hazards (e.g. nanoparticles, dusts, vapors)	Laser beam machining; Micro-soldering; Metal heat treatments	SR
Physical material treatment (laser applications) creating nanoparticles	Laser beam machining; Micro-soldering; Metal heat treatments	SR
Welding with high current creating EMF emission (especially in the automobile industry)	Arc welding; Resistance welding	SR
NER BIOLÓGICAL [2]	---	
NER PSYCHOSOCIAL [3]	---	
NER CHEMICAL [4]		
Welding aerosols produced at welding- and fame-cutting workplaces	Welding Processes; Oxy-fuel cutting	SR
Cutting fluids and mineral oil mist resulting from cutting fluids in metal processing and other workplaces leading to cutaneous diseases	Metal machining	SR CMC
Semi-conductor industry: exposure to metal fumes and dust leading to skin sensitization and respiratory diseases	Special processing and assembly technologies	SR CMC

Table 8. Identification of technological aspects (technical and material character) and biological aspects linked to AMP

TECHNOLOGICAL ASPECTS OF A TECHNICAL CHARACTER	Automation; Damping properties of anti-vibration devices; Electromagnetic Compatibility; Electronic Article Surveillance (EAS) and similar devices; Human-Machine-Interfaces; Latest generation of safety systems; New LED technology; New processes; New technologies; Personal Protective Equipment (PPE); Poor ergonomic design; Sources of ionizing radiation; Special Protective Clothing; Visual Display Units (VDU).
TECHNOLOGICAL ASPECTS OF A MATERIAL CHARACTER	Acrylate monomers (drying inks); Additives (food and textiles); Biocides; Bituminous materials; Combination of carcinogenic substances; Crystalline silica; Disinfection and cleaning agents; Endocrine disruptors; Enzymes; Epoxy resins; Hardeners (polymer production); Hydrocarbons mixtures; Isocyanates; Magnesium Alloys; Man-made fibers; Metals (ions of nickel, cobalt, chromium); New products and new applications; Nitrogen monoxide; Organic acid anhydrides; Organic solvents; Persistent Organic Pollutants (POP); Polymers; Powder paints; Replacements for trichloroethylene (degreasing); Reprotoxicants; Water-based paints and solvents
BIOLÓGICAL ASPECTS	*Aspergillus*; Bioaresoles and chemical risks; Endotoxins; Environmental allergens; Fungal Spores; *Legionella*; Molds; Mycotoxins.

Table 9. Identification of organizational aspects linked to AMP

NER PHYSICAL	Increased work-pace; Insufficient protection of high risk groups; Lack of physical activity; More hours (longer working hours); Older workers and physical demands; Poor awareness of thermal risks among low-status worker groups exposed to unfavorable thermal condition.
NER BIOLÓGICAL	Improper methods of measurement or measurement equipment / analysis to biological agents; Inadequate or lack of emergency preparedness and/or response plan concerning biological risks; Lack of information on biological hazards; Lack or poor maintenance of the workplace; Misunderstanding of hygiene; Poor risk assessment.
NER CHEMICAL	Importance given to psychosocial factors; Increasing importation of chemicals not complying with EU regulations; Migrant workers; Outsourcing (e.g. for cleaning and maintenance activities) performed by subcontracted workers with poor knowledge of chemical risks; Poor control of chemical risk (on SMEs); Workplaces poorly supervised.
NER PSYCHOSOCIAL	Aging workforce/ workers elderly population; Changing Contexts, new roles, skills, etc.; Disability; Emotional demands; Ethical Conflicts at Work; General deterioration of psychosocial working conditions, deteriorating industrial relations and social dialogue, interpersonal conflicts and problems, more individuality in the workplace; Imbalance/problems reconciling family and working life; Intensification of work, high workload / work pressure; Job insecurity; Lack of effectiveness of the OHS Management; Long working days; Mobility in the labor market; Unemployment, downsizing, difficulty re-entering the labor market / employability, job market unstable, precarious contracts, etc.; Violence and bullying; Vulnerability worker; Workers from other cultures; integration of people from other cultural backgrounds.

6. Discussion of results

Of the 171 identified NER, it must be first highlighted that physical and chemical groups account for 73% of NER, so generally the results depend largely on their characteristics. Applying the decomposition model (3), it is clear from the examples used and the results shown in Figure 2 that the distribution of the components is not uniform, not because the model does not allow it, but because of the limitations of those described as NER. This fact becomes more important when considering only the components of risk depending on the model (1) (excluding EX and CMC), thus verifying that the complete descriptions of the NER cannot be described, in most cases, as compliant with the definition of NER [7]. The results indicated, limit the analysis of the decomposition results, especially with regard to the identification of the NER directly linked to specific AMP. In this regard, apparent from Table 7, only eight NER have been identified of 171 analyzed, indicating that analyzing only the descriptions of the risks considered cannot establish a direct relationship to specific AMP. Thus, it has only been possible to obtain a small sample of AMP with potential to generate NER, since the 171 analyzed risks are in general terms compatible with AMP. Therefore, it is technically possible to establish links between these specific risks and AMP, but not directly, but through in-depth studies of each NER of interest which is beyond the scope of this paper.

However, with the identification of the technological aspects of the NER linked to AMP, a broader set of results have been obtained, that although do not allow the immediate identification of a specific processes, but indicate characteristic elements that can configure a policy framework AMP for identifying an indicative framework of potential NER. Therefore, as can be seen in Table 8, in addition to generic aspects of AMP such as new technologies and new processes, can be mentioned, by way of representative examples, technological aspects such as automation, as mentioned in a recent report of the EU-OSHA [6] or the man-machine interfaces, that have also been the subject of a specific study by the EU-OSHA on NER [11]. In relation to the identified biological contaminants it may seem difficult to establish a relationship between them and AMP, however sufficient bibliography exists for this purpose, to establish a starting point. For example, plastic forming processes or foundry processes through plastic and materials such as aluminum and steel respectively, can be sources of Aspergillus (among others) [12]. As for materials, a similar relationship can be made as in the examples mentioned. In this case nanomaterials should be also considered, although not shown in Table 8 because it has not been identified as such in the complete descriptions of the NER. It is indirectly included in the descriptions of the physical and chemical NER in relation to the generation of nanoparticles, this contaminant being the subject of other specific study by the EU-OSHA [13].

Finally, among the organizational aspects, can be highlighted those related to psychosocial NER, since by their general characteristics they are susceptible to be present in all AMP. However, establishing relationships between these aspects and specific AMP, normally depend both on the organizational characteristics of manufacturing systems where the AMP have been integrated. An example of the above aspects such as work intensification may be associated with process automation [14] Just in Time production [3], etc.

7. Conclusions

Complete descriptions of the NER analyzed, being susceptible to be present in general terms in the AMP, do not allow in most instances to establish direct links with specific AMP. However, as the main result of this investigation, it has been possible to identify, among such NER, a set of technological aspects, with which to establish a starting point to allow the identification of AMP that have the potential to generate NER, thus expanding the existing level of preventive knowledge in the field of manufacturing. With the results obtained it can be concluded that the AMP and NER are closely related. However, it has been possible to identify among such NER a set of technological aspects with which to establish a starting point to facilitate the identification of AMP potentially generators of NER. Thus, with the results obtained only it can be concluded that the AMP and NER are closely related. To determine a wide and specific set of AMP potential generators of specific NER it is necessary to develop scientific and technological studies to deepen knowledge of this binomial from the results obtained here. Such knowledge would be enhanced by adapting the descriptions of the risks analyzed to the model of NER (2).

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