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Analysis and Modeling of New and Emerging Occupational Risks in the Context of Advanced Manufacturing Processes

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Abstract

Besides traditional occupational risks, advanced manufacturing processes (AMP) can generate other risks described by the European Agency for Safety and Health at Work (EU-OSHA) as "new and emerging risks" (NER) to occupational safety and health. Several studies have been carried out by the EU-OSHA in order to identify all these risks.
However, the direct use of this set of NER in identification procedures of occupational risks, generally applied in labour processes and particularly in AMP, may result in the identification of traditional occupational risks rather than NER, mainly because they have been defined without following a risk reference model.
To solve this problem a risk model has been developed that improves and complements the NER definition of EU-OSHA, from which a second model has been developed to analyze the structure of the considered set of NER. It is observed that with the results obtained, the current descriptions of these NER do not explain their quality of "new and "emerging".

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

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1. Introduction

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). This raises new challenges for workers and companies, and in turn creates political demands, administrative and technical approaches that ensure high levels of safety and health at work (adapted from [1]).

The European Agency for Safety and Health at Work (EU-OSHA) [2, 3, 4], and the International Labour Organization (ILO) [5] indicate 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], "Green manufacturing technologies and processes, including robotics and automation" were selected from the eight new technologies that could help create NER in green jobs by 2020.

The basic definition of NER adopted by the EU-OSHA is "any occupational risk that is both new and increasing", taking the first steps by that agency for the identification of specific NER with the publication of four reports on the forecast provided by experts, being those that make up the framework of this study, covering physical risks [7], biological [8], psychosocial [9] and chemical [10], having been followed by numerous literature reviews and detailed reports designed to explore the main risks identified in the above projections [1].

1.1. Research problem

The direct use of NER included in the reference studies, often blurs between those coinciding with the traditional risks and those that can really be considered as new and emerging, according to the definition adopted by the EU-OSHA. This problem has its origin in that such NER do not follow a risk model reference, forming a structurally heterogeneous group which generally impedes any technical and scientific process towards the study of those characteristics of the occupational risk conferred by the qualities of "new" and "emerging".

1.2. Goals

The goal of this paper is to analyze and qualitatively model the concept of NER defined by EU-OSHA, whose results are consistent with the general procedures for the identification and evaluation of occupational risks with application to AMP.

1.3. Methodology

The methodology is based on the sequential development of the next set of steps: *Stage 1: Modelling of occupational* risk*:* it has been mainly based on the analysis of international reference standards and technical criteria of international organizations in the field of occupational safety and health (OSH); *Stage 2: Modelling of NER:* from the definition about NER given by the EU-OSHA [7, 8, 9, 10] and the results obtained in the previous step, we have analyzed and modeled the concept of NER; *Stage 3: Analysis of the composition of the NER:* it has been carried out in two phases: (Phase 1) has been identified the main NER considered by the EU-OSHA [7, 8, 9, 10]; (Phase 2) from the adopted NER model, we have analyzed the NER identified in phase 1; *Stage 4: Analysis of results:* we have analyzed the results obtained with the above steps from a qualitative statistical point of view.

2. Modeling of occupational risk

The overall process of risk assessment can be summarized as an overall process of hazard identification, risk analysis and risk assessment (adapted from e.g. [11]), forming part of that process of a risk management structure. The risk identification process includes identifying the causes and the source of risk, that is, the hazard in the context of physical damage [12]. Thus, it can be seen that for the correct identification of occupational risks in general, and the NER particular, it is necessary to properly distinguish between the concepts of "hazard" and "risk" because they do not always have the same meaning in all countries or in different scientific disciplines [13], even in many cases, including the field of OSH are confused or are considered synonymous (e.g. [14]).

In an analysis by Aven [15] on the concept of risk, indicating that it is impossible to present and discuss all definitions of this suggested and used concept in the scientific risk fields, therefore, in this work, a non-exhaustive reference is taken, a representative set of the definitions of "occupational hazard" and "occupational risk", using international standards ISO GUIDE 73 [16] and OHSAS 18001:2007 [17], as well as other definitions given by the EC [13], and some internationally recognized organizations in the field of OSH, namely: CCOHS [14], EU-OSHA [18], HSE [19] and NIOSH [20]. With the analysis of such a framework, it appears that in general, an occupational hazard is a source of potential harm. As for the damage, the OHSAS 18001:2007 [17] indicate that it understood in terms of human injury or ill health, or a combination of these. Other authors, for example CCOHS [14] add that the potential impact on organizations may be held in the form of loss of property or equipment.

2.1. Components of occupational risk

Within the development of the overall process of risk assessment, standard ISO Guide 73 [16], indicates that the risk identification step comprises of searching, recognition and description of risks,-the latter being the activity the structured representation of the risk, usually containing four elements: risk sources, events, causes and potential consequences. As for the risk analysis stage, ISO 31000 [21] indicates that it is possible to understand the nature of risk and determine the level of risk, defining this level as the magnitude of risk or combination of risks expressed in terms of the combination of consequences and their probability. In a more structured manner, EN 31010 [12] defines this stage of analysis as the process of consideration of the causes and sources of risk, their consequences and the likelihood that those consequences may occur. Similarly, standard OHSAS 18001 [17], risk is defined as the combination of the likelihood of an occurrence of a hazardous event or the exposure and the severity of injury or ill health that can be caused by the event or exposure. In this case, and as often happens, the risk is directly defined by the combination of the likelihood and severity variables [16, 22].

2.2. Occupational risk model

Known risk components, must be defined according to the objective of this work, being necessary for it complement the definitions given by the reference standards [16, 17, 21], given its generic nature in the context of risk management, by analyzing more specific sources in the field of OSH.

Definition 1. Source of risk (SR): hazard leads to a source of potential damage (adapted from [16]); may be the source: materials, equipment, methods or work practices [18]. And it is understood as damage: human damage or deterioration of health, or a combination thereof [16], besides being able to fall on someone, it could also do it something [14].

Definition 2. Cause (C): act or condition responsible for an action or outcome [20]. Or the facts that report on why they occur or may occur, both accidents and incidents (adapted from [23]).

Definition 3. Event (E): occurrence or change of a particular set of occupational circumstances which cause or may cause personal injuries through accidents, incidents and exposures to adverse situations (adapted from [16, 24, 25, 26]).

Definition 4. Consequences (CO): personal injuries: injury for occupational accidents; occupational diseases; fatigue; dissatisfaction, stress; nonspecific pathologies [27]. And the consequences of an incident: a result of any unexpected and unwanted event which may cause damage to property, equipment, products or the environment, production losses or increased legal responsibilities [23].

Definition 5. Likelihood (L): indicates the possibility that some event occurs that this possibility is defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general or mathematically terms (such as a probability or frequency over a period of given time [21].

As indicated, especially with ISO 31000 [21] and EN 31010 [12], as the process of risk identification is associated with four characteristic components, and to the subsequent risk analysis is carried out joint assessment of the likelihood and consequences of the identified risks, can be considered that the risk is further configured by a fifth component, namely the likelihood. Thus, it can be described as the risk model according to Definition 6.

Definition 6. 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).

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

3. Modeling of NER

The complete definition of NER given by the EU-OSHA is the following [7, 8, 9, 10]:

Definition 7. NER: any occupational risk that is both new and increasing:

- By «new» we mean that:

C1. the risk did not previously exist and is caused by new processes, new technologies, new types of workplace, or social or organisational 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 the:

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).

Because NER is the definition of "any occupational risk that is both new and increasing", it follows that for a given configuration NER must be satisfied at least one of the conditions that determine a new risk (coded C1 to C3) and another -at least- of the conditions relating to when a risk is increasing (coded C4 to C6). Unlike the original sources cited, has carried out the codification of the so called along the paper as "conditions" that define an NER

Thus, being N is the set of conditions that define a new risk (N = {C1, C2, C3}) and I the set of conditions that define an increasing risk, (I = {C4, C5, C6}), the cartesian product of the sets N and I is equal to the set of all ordered pairs (n, i) that can be formed with the conditions that meet the definition of NER; it may be expressed as (2):

$$NxI = \{(n, i): n \in N, i \in I\} \quad (2)$$

Therefore a particular occupational risk (R) belongs to the set of NER if and only if its components satisfy at least one ordered pair (n, i) of the 9 possible (3 x 3), as shown in example 1.

Example 1: “Complexity of new technologies, new work processes and human-machine-interfaces leading to increased mental and emotional strain” [7]: from the definition itself of this NER it follows directly that it satisfies C1 due to the existence of new sources of risk. Moreover, it also follows directly that C6 is satisfied, because there is an increase of mental and emotional strain. Therefore, and taking into consideration as the only source of information the complete description of the NER itself, it can be deduced that it complies with the ordered pair (C1, C6). This example is one of the exceptions that permits the conclusion with the analysis of the actual description of the risk that it really is a NER. In many other cases it is not impossible, as it follows easily from Example 2.

Example 2: *"Powder paints used in painting/coating installations*" [10].

3.1. Components of NER

To study in all its amplitude the definition of NER and to be able to model it, it is necessary to analyze it and how to proceed, the relationship between the conditions that configure that definition and the components of the risk model (1), whose results are shown in Table 1.

- C1: the elements contained in this condition form part of those contained in the definition 1 source of risk, so that when it indicates that the risk is caused by those elements two possible interpretations exist, or the risk is generated by these new sources, or that the risk is explained by new causes. Therefore, since these two interpretations fit, it will be these two components which are related to C1
- C2 and C3: of the six conditions considered, these two are especially difficult because they do not fit clearly into any of the definitions used as a reference, thus resulting in more analysis. Thus, when with these conditions a persistent problem is indicated or new scientific knowledge allows a long-standing issue to be identified as a risk, it is clear reference to a known occupational circumstances which cause or may cause injury, damages considered as such from a change in social perceptions or public or new scientific knowledge. Moreover, these new events and new consequences will logically originate from any kind of source of risk and may be already known as a source or a long-standing issue becomes identified as a source of risk. In the first case we would be looking at a source of risk in addition to the events and consequences already known to have been associated new events and / or new consequences, and in the second case would be a new actual source configured not new elements, and characterized by generating new events and / or new consequences. Deduction equivalent to the component follows the causes. Therefore, based on the arguments made, considering the result of the persistent problem and previous question, new events and / or new consequences can also be considered under these conditions the existence of new sources of risk and new causes, unlike C1, will be integrated in processes, technologies, workplaces, or social or organizational structures already known
- C4: in this case, given that the condition depends on the number of hazards, there is a direct relationship with the sources of risk component
- C5: similarly to the previous condition, because the condition is associated directly to the likelihood, relation to the component is immediate

- C6: this condition refers directly to the health of workers, namely the personal injury of workers, and thus is also associated immediately with the consequences component

Table 1. Relationship between components of risk (1) and the conditions that define a NER (definition 7).

COMPONENTS OF RISK	CONDITIONS THAT DEFINE A NER					
	NEW (N)			**INCREASING (I)**		
	C1	**C2**	**C3**	**C4**	**C5**	**C6**
SR	●	●	●	●		
C	●	●	●			
E	●	●				
CO	●	●				●
L					●	

3.2. NER model.

The relationships shown in Table 1 between the set of components of risk (1) and the set of conditions that define a NER (Definition 7) can be expressed as follows: R being the set of components that configure the risk (SR, C , E, CO, L), and C being the set of conditions that define an NER (C1, C2, C3, C4, C5, C6), the cartesian product of the sets R and C is equal to the set of all pairs ordered (r, c) that can be formed by linking the components of risk and conditions, it may be expressed as (3):

$$R\ x\ C = \{(r, c): r \in R, c \in C, \} \quad (3)$$

Of all ordered pairs algebraically possible (3) only those subsets compatible under the definition of NER are of interest, as referred to in Table 1. Thus, being N (N ⊂ RxC) the subset of all ordered pairs that satisfy the conditions that can define a new risk: $\mathrm{N} = \{(\mathrm{SR}, \mathrm{C1}), (\mathrm{SR}, \mathrm{C2},), (\mathrm{SR}, \mathrm{C3}), (\mathrm{C}, \mathrm{C1}), (\mathrm{C}, \mathrm{C2}), (\mathrm{C}, \mathrm{C3}), (\mathrm{E}, \mathrm{C2}), (\mathrm{E}, \mathrm{C3}), (\mathrm{CO}, \mathrm{C2}), (\mathrm{CO}, \mathrm{C3})\}$ and being I (I ⊂ RxC) the subset of all ordered pairs that satisfy the conditions which may define a risk that is increasing: $\mathrm{I} = \{(\mathrm{SR}, \mathrm{C4}), (\mathrm{CO}, \mathrm{C6}), (\mathrm{L}, \mathrm{C5})\}$, the NER model may be described with the definition 8.

Definition 8. 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 (4).

$$\mathrm{R} \in \mathrm{NER\ iff} \ \exists\ (\mathrm{r}, \mathrm{c}) \in \mathrm{N\ and} \ \exists\ (\mathrm{r}, \mathrm{c}) \quad (4)$$

4. Analysis of the composition of the NER

In this section the two phases performed to analyze the composition of the NER are described, along with the main statistical results obtained.

4.1. Phase I. Identification of NER

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 [28] 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". Thus the set of NER identified, does not fit a model of reference risk, nor maintain a homogeneous structure, as it is initially clear from a simple reading of his complete descriptions, which can be seen directly, in broad terms, that they are in some cases extensive, detailed and specific (example 3), and others are small, short and generic (example 4).

Example 3: *"Increasing use of magnesium alloys in the construction of cars, railway coaches and other machinery which makes them highly flammable and very difficult to extinguish, thus enhancing the risks not only for the fire brigades but for everybody involved"* [10].

Example 4: *"Combined exposure to noise and vibration"* [7].

4.2. Phase II. Descomposition of the NER

When the concept of NER has been analyzed, it has been assumed that all NER is capable of adapting to the Risk model (1), an assumption that will be verified in the following section for all NER identified. For this verification, it has been developed from the NER model (4) a new model with which to analyze and decompose the NER, and can be described with the definition 9.

Definition 9. 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 (E) and characteristic manufacturing context (CMC) may be expressed as (5). Thus, all information contained in the complete description of all NER, will be assigned to any of these variables (variables can be unassigned), as shown in Example 5 (Table 2).

$$Descomposed\ NER\ = (R, CI) \tag{5}$$

Table 2. Example 5 of a deseomposed NER.

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

The application of the Decomposition model (5) on all identified NER will allow for the verification of both the validity of the NER model (4) as to analyze the structure and composition of these risks. For it has decomposed each NER following the methodology proposed by Brocal [29], which can be summarized indicating that the same variables that configure the complete description of each NER, have been obtained based on the definitions of 1 to 5 for the case of risk components (1); and in the case of the complementary information (CI) have also followed the following criteria: E: when the complete description of the NER explicitly includes examples, it is these that are associated with this variable (usually the examples complement some of the components: examples of sources of risk, examples of consequences, etc.); CMC: is included in this component the productive context when the complete description of the NER includes it, not as an example but as the characteristic itself, understood as the sector, workplace or production process (as shown in example 5). Note that the interest of distinguishing between risk components (1) and complementary information (CI) lies mainly in identifying the components that configure the NER as risk itself.

4.3. Statistical results

171 NER has been identified, distributed in groups with the following absolute frequencies: 58 physical NER [7]; 19 biological NER [8]; 27 psychosocial NER [9] and 67 chemical NER [10]. In this regard, given the objectives of the present work, the set results are of interest, bearing in mind that they are strongly determined by the characteristics of the first two groups and represent 73% of total NER. This set of NER has been decomposed individually according to the Decomposition model (5), 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 (CTE) risk has been identified (true) or not identified (false) in each decomposed NER, using the following code: = true CTE ; false = $\overline{CTE}$.

For the purposes of the analysis of the frequencies associated with CTE variable, five risk components that configure the NER itself (SR, C, E, CO, and L) are of interest, for which their first and fifth order frequencies have been studied. With the first order the composition of the NER (for the four risk groups) has been analyzed by counting each (true) component individually identified, obtaining the following absolute frequencies as shown in Figure 1(a): SR=127; C= 84; CO= 57; L= 40; E = 22. And with the fifth order frequency, a similar analysis has been carried out, but in this case considering the absolute frequencies associated with each combination (32 possible) identified from the five components, $n(SR_i\ C_i\ E_i\ CO_i\ L_i)$, it can be observed in the abscissa axis of Figure 1 (b) "i" takes the value according to the 32 possible frequencies, with 0 to $n(\overline{SR_0}\ \overline{C}_0\ \overline{E}_0\ \overline{CO_0}\ \overline{L_0})$ and 31 for $n(SR_{31}\ C_{31}\ E_{31}\ CO_{31}\ L_{31})$. For example, the combination i = 16 ($SR_{16}\ \overline{C}_{16}\ \overline{E}_{16}\ \overline{CO_{16}}\ \overline{L_{16}}$) corresponds to an absolute frequency of 36 counts.

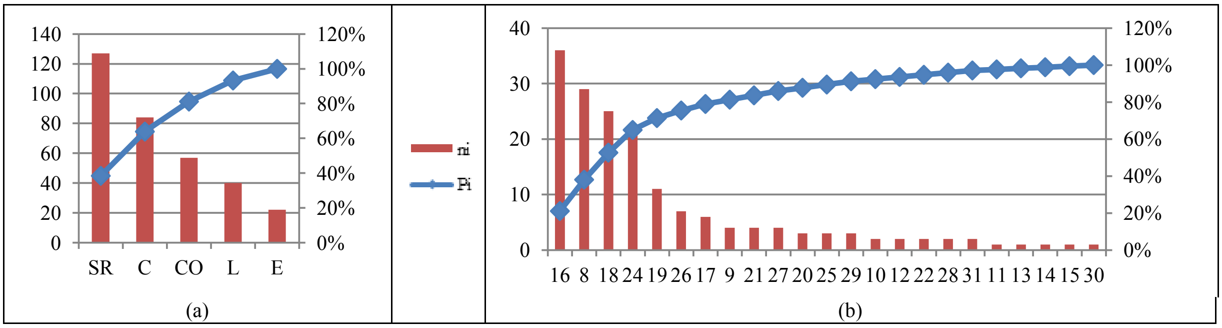

Fig. 1. Pareto Charts (ni: absolute frequency, Pi: cumulative percentage) of the distribution of NER components: (a) first order frequencies; (b) fifth order frequency.

From the results of the analysis of the frequencies the first order shows that SR has been identified in 74% of analyzed NER, C in 49%, and the other components in percentages between 13% and 33%. Thus, the major components are SR and C, representing 64% of the cumulative percentage. And of the total components identified, representing 39% versus 61% of those not identified ("ideally", if all NER was described with the five components of risk, the identified components represent 100%). As to the results of the analysis of the frequencies of the fifth order of the 32 possible frequencies, 23 in total have been identified, so that 5 frequencies (22% of these 23 frequencies, for i = 8, 16, 18, 19, 24) represents the configuration of the 72% of total NER identified, being (from highest to lowest ni): $SR_{16}\ \overline{C}_{16}\ \overline{E}_{16}\overline{CO_{16}}\ \overline{L_{16}}$ (21%); $\overline{SR_8}\ C_8\ \overline{E}_8\overline{CO_8}\ L_8$ (17%) ; $SR_{18}\ \overline{C_{18}}\ \overline{E_{18}}\ CO_{18}\ \overline{L}_{18}$ (15%); $SR_{24}\ C_{24}\ \overline{E}_{24}\ \overline{CO_{24}}\ \overline{L}_{24}$ (13%) y $SR_{19}\ \overline{C_{19}}\ \overline{E_{19}}\ CO_{19}\ L_{19}$ (6%).

As for the sets of frequencies of fifth order formed according to the number of identified components, 75% of all identified frequencies are composed of one or two components, expanding to 94% if three components are considered, so that the frequencies formed by four and five components are residual.

5. Discussion of results

The NER model proposed (4) complements the definition given by EU-OSHA, largely eliminating the identified limitations, so that they tended to disappear, adjustments should be made in conditions 1, 2 and 3 defining a "new" (subset N), so that relations with the risk components are direct and strong, aspects which are outside the scope of this study, since the modeling carried out has been made from the analysis and interpretation of existing information, thereby avoiding modification.

It has been proved that the Decomposition model (5) is applicable to the complete description of all NER identified in phase 1, leaving no case risk information unrated (as risk component (1) and / or CI). Thus, the immediate result obtained is that the distribution of the components of risk is not uniform (SR was identified in 74% of analyzed NER, C in 49%, and the other components in percentages between 13 % and 33%). In this regard, 38%

of the frequencies of fifth order are composed of a single component and 37% of two components, exponentially decreasing these percentages as the number of components considered, so that the NER set of five components only represent 1% of cases (for i = 31). Thus, with only 5 frequencies the structure of 72% of all NER identified can be explained. As for the remaining 28% of NER, is characterized by a greater heterogeneity, because its configuration depends of 18 different frequencies.

Ideally, all complete descriptions of the NER should be configured at least to those components that fit the NER model, namely, those that give them the quality of "new" and on the "increase". However, it has been found with the decomposition performed by (5) and analysis of the different frequencies of fifth order obtained, these descriptions do not explain themselves, in general, compliant with the definition of NER. The most obvious case is observed with NER configured with fifth order frequency $\overline{\mathrm{SR}}_8\ \mathrm{C}_8\ \overline{\mathrm{E}}\ {}_8\overline{\mathrm{CO}_8}\ \overline{\mathrm{L}}_8$ (17%), where in the best case, these NER would comply with the condition to be associated with "new" causes, but lacking other components that could relate to any of the conditions that define a risk on the "increase" it may not in any case be said that complete descriptions of these risks explain the condition "new" and "increase". However, although other configurations (83%) are susceptible to adapt to NER model, it cannot be concluded in general from the only description of the components identified, that they fulfill the necessary conditions, since it should be accompanied explicitly by those descriptions configuring it as "new" and / or on the "increase".

From all the above, highlights the fact that the current configuration of the NER collected the reference studies [7, 8, 9, 10], in general terms prevents the precise study of those characteristics that give them the quality of "new and "emerging", hindering future developments in the field, such as simulation models for the identification and risk assessment as proposed Sekulova and Simon [30].

6. Conclusion

The definition 7 given by the NER EU-OSHA can be considered inadequate due to the different conditions that configure it in terms of "new" and "emerging" do not follow a risk model with which to relate risk components involved. However, the NER model (4) developed, consistent with the general procedures for the identification and evaluation of occupational risks, can complement and clarify such definition without changing the information contained in it. With regard to the decomposition NER model (5), it appropriately explains the structure and composition of all NER considered in the reference studies [7, 8, 9, 10], however it is not possible to determine from the results obtained if each NER also meets the definition 7 of EU-OSHA, in other words, current descriptions of these NER do not explain their quality of "new and "emerging", not because the model does not permits it , but because in general, the complete description of the NER does not provide the necessary information and there is thus a blurring of lines between traditional risk and NER, hampering the design of technical and scientific strategies focused on new and emerging aspects of interest. This problem can be solved adopting and implementing the proposed NER model (4) for both NER considered in this study, as especially for those that are identified in the future. Everything indicated is especially relevant for the AMP, since, for example, such processes are among the eight new technologies that could help create NER in green jobs by the year 2020 [6].

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