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Managing Human Factors to Reduce Organisational Risk in Industry

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Abstract: Human factors are intrinsically involved at virtually any level of most industrial/business activities, and may be responsible for several accidents and incidents, if not correctly identified and managed. Focusing on the significance of human behaviour in industry, this article proposes a multi-criteria decision-making (MCDM)-based approach to support organizational risk assessment in industrial environments. The decision-making trial and evaluation laboratory (DEMATEL) method is proposed as a mathematical framework to evaluate mutual relationships within a set of human factors involved in industrial processes, with the aim of highlighting priorities of intervention. A case study related to a manufacturing process of a real-world winery is presented, and the proposed approach is applied to rank human factors resulting from a previous organisational risk evaluation from which suitable inference engines may be developed to better support risk management.

Keywords: human behaviour; organisational risk; multi-criteria decision-making; DEMATEL; bottling process

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1. Introduction

Companies are managed by following previously designed strategies, and operate according to processes implemented on the basis of the available resources. These strategies and processes are complex systems that integrate workers, plants and environment. Balancing and mutually adapting these elements make it possible, among others, to implement actions aimed at preventing the occurrence of accidents and occupational disease within workplaces, and also to identify near misses. The concept of human management system (HMS) is important to this issue.

Clerici et al. [1] affirm that an organization is a plurality of "human elements", and risks often depends on organizational criticalities, whose reduction can be undertaken by implementing effective human resource management (HRM). In particular, HRM is defined as a system of structured procedures aimed at optimizing the manpower management in a company [2], with its workers being the most valuable assets of the organisation [3]. As asserted by Cirjaliu and Draghici [4], nowadays companies seek to continuously improve the well-being and satisfaction of their human resources within their own operational environments.

An important aspect to take into account within this context is the integrations of human factors and ergonomics (HF/E), whose optimal management is crucial to achieve central objectives, for instance the transition to sustainable development [5,6].

Indeed, human factors are intrinsically involved at virtually any level of most industrial/business activities [7,8]. They represent the core component of many organisations and may be responsible for several accidents and incidents if not correctly identified and managed, as asserted by Ergai et al. [9]. However, as authors underline, investigating these aspects depends on the specific features of the workplace of reference, and on the evaluator's background. For this reason, promoting a safe and environmentally responsible manner of working represents one of the most important organisational challenges, currently [10].

The importance of this concept is broadly shared in the literature. Wilson [11] asserts that any understanding of system ergonomics must be related to the idea of system engineering. Hassall et al. [12] stress that analyses based on human factors and ergonomics are commonly used to improve safety and productivity—particularly in complex systems. Sobhani et al. [13] underline that the improvement of workplace ergonomic conditions gives opportunities to better deal with production variations and optimize the performance of system operation.

To address the aspects related to HF/E within industrial workplaces, the decision-making trial and evaluation laboratory (DEMATEL) method, first developed by Fontela and Gabus [14,15], is herein suggested as a mathematical framework to evaluate mutual relationships among some of the most important human factors involved in industrial processes—which, as in many other areas, have usually shown to be deeply intertwined and mutually affected.

Amid various multi-criteria decision-making (MCDM) methods proposed in the literature, DEMATEL is particularly helpful to take into account existing interdependence among the main elements involved in any complex decision-making problem, on the basis of judgments attributed by a team of experts. DEMATEL also finds the central criteria to represent the effectiveness of factors/aspects, and avoids evaluation overfitting. This interdependence is eventually represented by means of a graphical chart, from which causes, and effects, are suitably described.

The present paper is organised as follows. Section 2 discusses human factors and ergonomics in industrial environments. The main investigated areas when leading organisational risk assessment are presented and described. Section 3 deploys the DEMATEL framework, with its various methodological steps, and the obtained outputs. Section 4 presents a real-world case study of a manufacturing process led in a winery: The bottling process. The most critical human factors, emerged from a previous implementation of risk assessment [16], are ranked by means of the DEMATEL to suggest an order of intervention aimed at gradually reducing organisational risk in the analysed operational context. Lastly, conclusions are provided in Section 5 to close the paper.

2. Human Factors and Ergonomics in Industry

Amount and intensity of human interactions with industry processes generally depend on the field in which the organisation operates. Carpitella et al. [17] presents a literature review in this regard, which is herein extended. Saravia-Pinilla et al. [18] analyse the strong bond existing among environmental and human factors. In particular, the authors highlight a gap in the existing literature about this topic, and propose a model combining human and environmental factors with relation to the processes of product/service design and an ad hoc development to potentiate decision-making processes.

A tool that is particularly effective in conducting human factor-based analyses for reducing accidents and incidents is represented by the human factor analysis and classification system (HFACS), developed by Wiegmann and Shappell [19]. This can be applied in a wide variety of contexts, such as, for instance, aviation industry [20] or maritime safety [21]. Chen et al. [22] focus on marine casualties and incidents and deal with human factor management with the aim of reducing accidents and avoiding disasters. The authors implement the framework HFACS for maritime accidents (HFACS-MA), a useful support to increase the level of safety and reduce human errors by identifying possible accident causes. Madigan et al. [23] refer to the rail industry and stress the importance of carefully taking into account also latent factors. They propose HFACS by accomplishing a retrospective analysis to examine causes of minor incidents to prevent future and more severe events.

It is neither possible, nor convenient, to totally eliminating human contribution to processes, even when a high degree of automation is pursued, such as in manufacturing industries [24]. Industries with high production volumes may consider machines and computers as faster and more reliable than humans in leading automatic operations. In this case, the human contribution given to automated processes would be barely necessary, and this may help reduce possible errors, due to psychological and physical factors, such as health, stress, age, mood, and so on. Moreover, the more customised the manufacturing process, the more crucial the role of human factors.

Furthermore, the aspect of dependence among various phases of a process has to be considered and managed. This kind of dependence strongly impacts on the reliability level, as asserted by Zio et al. [25]. Indeed, considering, for instance, a sequence of two interdependent tasks, a fault on one of them increases the probability of failing on the other. The authors propose a framework based on a fuzzy system for eliciting expert knowledge about those factors mostly influencing dependence between two successive tasks. In particular, relationships between the input factors and the conditional human error probability are represented by means of a set of transparent fuzzy logic rules, and an application, related to two tasks required in response to an accident scenario at a nuclear power plant, is analysed.

Therefore, a current challenge faced by organisations consists in integrating even more machines and workers [26], with the aim of creating a systematic operational environment and optimising all the available resources. In this context, human reliability strongly influences organisations' outcomes, and plays an important role in evaluating risks related to industrial/business activities.

Human reliability refers to the field of human factors and ergonomics, and is defined as the probability to successfully carry out a general human activity [27]. Human performance, as expressed before, can be influenced by such factors as age, physical and psychological health, attitude, etc. For this reason, human reliability is assessed with the aim of supporting risk evaluation and, in particular, of determining the impact of human contribution to the risk of failure or success, especially when humans are directly responsible for system operation, as it is usual today.

Since diverse factors are involved within the operation of systems or processes under analysis, a multidisciplinary approach is necessary to prevent the possible occurrence of human errors. Generally, human errors [28,29] are classified into errors of commission (EOC) and errors of omission (EOO). The first group is related to errors during the phases of identification, interpretation and execution of a specific activity, whereas the second category regards errors, due to forgetfulness or inattention, omitting a step of the task or also the whole task itself.

Triggers for faults are likely represented by human factors, the evolution of the error probability can be understood and approached by modelling human behaviour. Human behaviour can be schematised according to various levels, classified as skill-based, rule-based and knowledge-based [30]. By transiting from the first level to the third, the human error probability (HEP) increases. Specific errors are associated to each kind of behaviour [31]. In particular, the main causes of errors related to skill-based behaviour are the lack of concentration and the presence of stressful situations. Concerning the rule-based level of behaviour, errors derive from wrong approaches to procedures and rules. Lastly, regarding the knowledge-based behaviour, errors are caused by incorrect interpretations of specific situations or also by incomplete knowledge.

On the basis of all the above, organisational risk assessment in industrial environments is conducted with the aim of evaluating, eliminating or at least minimising risks related to ineffective manners of work, in terms of methods and operation management from humans. Such kind of risks derives from psychological and physical conditions that negatively impact on the quality of work and life.

In particular, when leading organisational risk assessment, the main areas presented in Table 1 are analysed with a deep level of detail. The purpose consists in highlighting the presence of possible stressful aspects related to human factors and ergonomics within each area, which could potentially damage the global wellness and health of workers, and therefore, the performance of the whole organisation.

These factors are present in almost all the working environments. Among all organisational aspects, the European agreement on work-related stress held in Brussels in the year 2004 [32] underlines as managing the problem of stress at work leads to greater efficiency and improvement of health and safety conditions, with consequent economic and social benefits for companies, workers and society. For this reason, the same agreement established to offer models and guidelines for evaluating work-related stress on the basis of two phases, namely preliminary assessment and in-depth evaluation. The first phase is based on the identification of verifiable and quantitative stress indicators. The second phase should be undertaken through surveys, focussing on groups and semi-structured interviews to homogeneous groups of workers.

Table 1. Description of investigated areas related to human factors and ergonomics.

ID	Investigated Area	Description
A_1	Organizational culture and role	Sharing values, upon which the organisation policy is grounded; maintaining relationships among different levels of the same organization; being aware about the own role within the company.
A_2	Career development and job stability	Having clear the possibilities of development in terms of career advances; knowing the path of professional growing; achieving contractual stability.
A_3	Communication, information, consultation and participation of workers	Empowering communication among all the levels of the hierarchy structure of the company; involving workers within decision-making processes to pursue general business objectives.
A_4	Training, awareness and competence	Promoting training paths aimed at increasing specific competencies of workers and at continuously improving the level of safety and security related to industrial processes.
A_5	Operational control: Indication of measures and instruments	Defining scheme, minimum contents and work procedures to lead a safe execution of the main tasks; identifying the main criticalities to be monitored; monitoring and controlling processes and outputs; planning and implementing maintenance interventions on the basis of the policies undertaken by the organisation.
A_6	Extraordinary situations and changes management	Defining criteria, methods and responsibilities to identify possible scenarios of extraordinary situations causing exceptional or unusual results; establishing intervention measures; managing changes to implement corrective measures.
A_7	Outsourcing and interference management	Evaluating direct and indirect impacts of the outsourcing process; implementing a framework of cooperation with external companies to optimise safety both of internal workers and third parties.
A_8	Workload and working hours	Examining the entity of workload; balancing responsibilities related to each group of workers; managing and correctly planning the number of working hours per person; integrating work with life and social contexts of workers.

By analysing the results coming from such evaluations, we propose to focus on the more critical human factors emerged for each target area (Table 1). With this aim, the DEMATEL methodology is suggested to select, within the set of highlighted human factors, those most influencing the others. This approach is useful to suggest an order in planning and implementing mitigation measures of organisational risk.

3. DEMATEL to Increase the Level of Safety in Industrial Processes

In complex systems, many aspects, factor or criteria are, either directly or indirectly, deeply intertwined (sometimes in a hidden way), and mutual interference affects other elements, thus making it difficult to find priorities for action and eventually hindering decision-making. In many cases, pursuing a specific objective may inadvertently impair several other objectives. Therefore, having a clear vision of the system contributes to the identification of workable solutions. DEMATEL has shown to help confirm interdependence among variables and restrict the relation that reflects the characteristics of a system of management trend [33–35]. DEMATEL's outcome is a visual representation, through which decision-makers may organize better the actions to take. The purpose of the use of DEMATEL in this paper is to discern the direction and intensity of direct and indirect relationships that flow among a number of well-defined elements. Thus, experts' knowledge is used to contribute to better understand the problem components and the way they interrelate.

The DEMATEL technique can be implemented by means of seven steps, in sequence.

1. The problem under analysis has to be clearly expressed in terms of a general goal. The main elements/factors characterising the problem have to be defined by means of the support of a decision-making team composed of experts in the field.
2. Non-negative matrices $X^{(k)}$ have to be produced, where $1 \leq k \leq H$, H being the number of experts, expressing judgments on the mutual influence between pairs of elements. Elements $x_{ij}^{(k)}$ $i, j = 1, \ldots, n$ (n being the number of compared elements) represent the numerical values encoding the judgments. The meanings of those numerical values are defined as follows: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), 4 (very high influence). The main diagonal values of any of these matrices are zero.
3. The direct-relation matrix A has to be built. This matrix incorporates all the matrices previously filled in by the involved experts. A is a square matrix of order n that averages the opinions of the group of experts:
$$A = \frac{1}{H} \sum_{k=1}^{H} X^{(k)}. \tag{1}$$
4. The normalized direct-relation matrix has to be obtained. From (1), this matrix is calculated as
$$D = sA, \tag{2}$$
where s is a positive number slightly smaller than
$$\min \left[\frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}}, \frac{1}{\max\limits_{1 \leq j \leq n} \sum_{i=1}^{n} a_{ij}} \right]. \tag{3}$$
Based on matrix D, the initial influence that elements exert on and receive from the others is shown. Then, a continuous decrease of the indirect effects among the considered elements may be obtained along the consecutive powers of matrix D. This enables to obtain the total relation matrix, as explained next.
5. The total relation matrix T has to be calculated. This matrix reflects both direct and indirect effects among elements, and is achievable through the sum of the powers of matrix D. Observe that $\lim\limits_{n \to \infty} D^n = 0$, since the spectral radius of D is smaller than 1, since, by Equation (3), it is bounded by the maximum row and column sum. As a result, see, for example, Example 7.3.1 in [36], the power series of D, $I + D + D^2 + \cdots$, converges to $(I - D)^{-1}$ where I is the identity matrix of size n. Consequently, the total relation matrix may be written as
$$T = D(I - D)^{-1}. \tag{4}$$

As said, this matrix represents the build-up of mutual direct and indirect effects among elements. Observe that the diagonal entries of matrix D (accounting for the direct effects) are zero; however, the diagonal elements of T collect all the non-direct effects associated to their corresponding factors. This fact is crucial in step 7.

6. An influential relation map is obtained through the definition of $\mathbf{r} = (r_i)$ and $\mathbf{c} = (c_j)$ as $n \times 1$ and $1 \times n$ vectors, respectively representing the sum of the rows and the sum of the columns of the total relation matrix T. Particularly, r_i represents both direct and indirect effects of element i on the others, whereas c_i summarizes both direct and indirect effects of the other elements on element i. In such a way, the sum $r_i + c_i$ gives the overall effect (prominence) of element i, and the subtraction $r_i - c_i$ helps in dividing the elements into cause and effect groups (relation). Prominence allows to rank factors according to their global influence, while relation enables to group elements into the cause group—if the subtraction is positive—, and into the effect group—otherwise.
7. Prominence ranking gives crucial information on the impact associated to the factors. However, a cutoff on the factor list is performed through a suitable threshold, bearing in mind that if the threshold is too high important factors may be excluded and if it is too low, too many factors—some of them irrelevant—may be included, which will turn the solution too complex and thus impractical. In the literature, the threshold value is determined in a variety of ways: By experts through discussions [37,38] or brainstorming techniques [39], by following results of literature review, the maximum mean de-entropy (MMDE) [40], the average of all elements in the matrix T [41], among others. In this paper we use this last value. Finally, a causal diagram chart is drawn by mapping the dataset of $(r_i + c_i,\ r_i - c_i)$, which gives a graphical representation of the main interrelations among factors. Typically, only the interrelations among factors considered within the cutoff are drawn, for the sake of clarity.

The main goal of the DEMATEL application in the present paper consists in identifying key factors based on the causal relationships and the degrees of interrelationship between them, with the aim of providing companies with a structured way of understanding the nature of interdependencies within a set of human factors. As previously asserted, the definition of human factors results from a previous context evaluation carried out in terms of an organizational risk analysis. In other terms, we aim to identify aspects influencing the others and aspects being influenced by others for pursuing a higher level of safety and security in leading industrial processes. To demonstrate the usefulness of our approach, a real-world case study is developed to evaluate interdependencies among critical human factors analysed in a manufacturing process of a Sicilian firm with the aim of reducing organizational criticalities.

4. Real-World Case Study of a Sicilian Winery

The case study refers to a manufacturing firm, a winery located in Trapani, Sicily (Italy). We aim to focus on the wine bottling process carried out in the company. This process is composed of 13 different phases, provided in Figure 1, and takes place in the area dedicated to delivery and production. In the mentioned area, there are three fixed stations and a movable position, respectively occupied by the following operators:

1. W_1, worker dedicated to control that bottles are filled in and plugged;
2. W_2, worker dedicated to control the global quality of bottles;
3. W_3, worker dedicated to wrap final products;
4. W_4, worker dedicated to carry out the following two activities: Raw materials (empty bottles, labels and corks) and packaging supply; handling of wrapped final products.

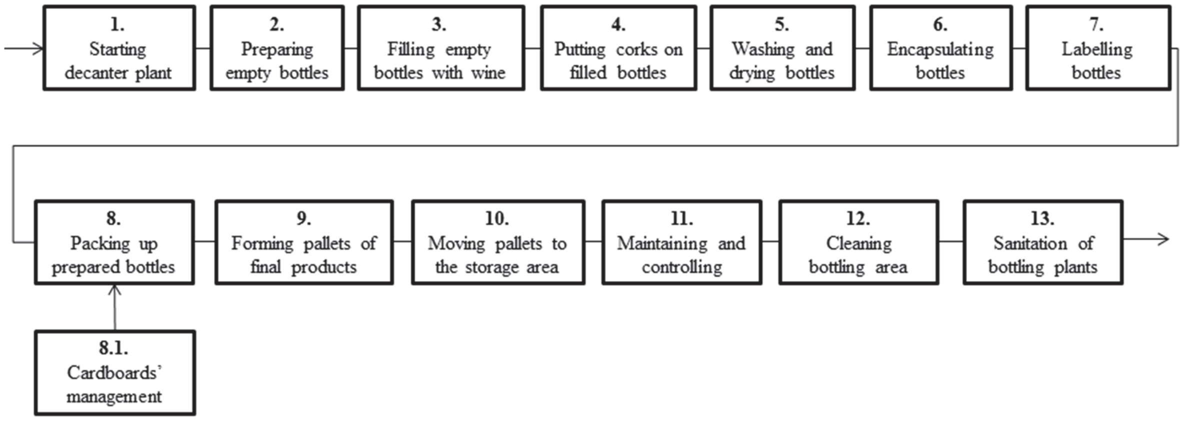

Figure 1. Phases of the bottling process.

The scheme of the production line representing the bottling process is shown in Figure 2. The stations indicated as "DP" and "P", respectively, represents the point in which empty bottles are first taken off from pallets (in which they were originally stocked) for starting the bottling process, and the point in which bottles (after having been filled in, plugged and checked) are finally put in pallets and wrapped to be sent to the storage or final customer areas.

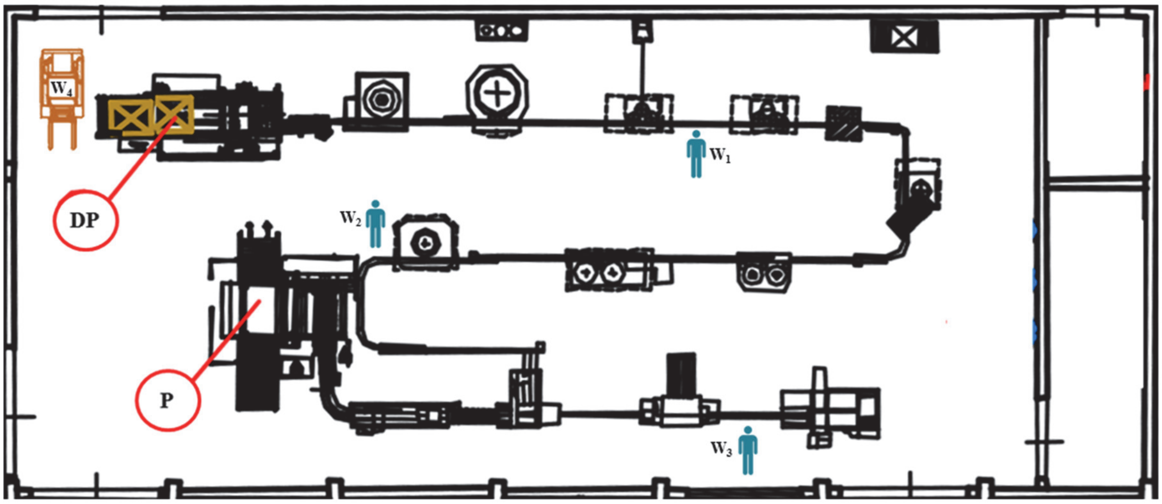

Figure 2. Scheme of the production line representing the bottling process.

With relation to the described process, the firm recently undertook an organisational risk assessment by focusing on the group of workers distributed in the interested zone. In particular, the work-related stress was evaluated by adopting the guidelines provided in 2011 by the National (Italian) Institute for Insurance against Accidents at Work [16]. Within that evaluation, the areas of Table 1 were deeply investigated by means of detailed surveys with the workers. These surveys aimed at highlighting the possible presence of critical human factors for each area, with the final purpose of managing critical aspects and then reducing the organisational risk as much as possible. In particular, the 16 human factors in Table 2 (listed with relation to their related area) emerged as possible sources of problems. The application of the DEMATEL methodology is suggested for establishing an order for implementing mitigating measures.

Table 2. Critical human factors related to each area.

ID	Investigated Area	Description
A_1	Organisational culture and role	• **HF_1** System of security and safety management not implemented; • **HF_2** Ethical and behavioural code not implemented.
A_2	Career development and job stability	• **HF_3** Criteria for career advancement are not defined; • **HF_4** Reward systems related to the correct management of human resources are not defined for supervisors; • **HF_5** Reward systems related to the achievement of security objectives are not defined.
A_3	Communication, information, consultation and participation of workers	• **HF_6** Work may depend on tasks previously accomplished by others; • **HF_7** Tools involving workers within decisions and strategies are not implemented; • **HF_8** Rigid protocols supervising and controlling workers are implemented.
A_5	Operational control: Indication of measures and instruments	• **HF_9** Workers are exposed to noise between the I and the II levels of action; • **HF_{10}** Inadequate ventilation and microclimate; • **HF_{11}** Inadequate lighting; • **HF_{12}** Workers may be exposed to the risk of recurring movements.
A_8	Workload and working hours	• **HF_{13}** Unpredictably variations of workload; • **HF_{14}** Workers cannot regulate machines' rhythm; • **HF_{15}** Workers lead tasks having high level of responsibility for stakeholders, plants and production; • **HF_{16}** Shifts may be not well organised.

We apply now the DEMATEL to evaluate existing interdependencies within the set of $n = 16$ human factors detailed in Table 2. Five experts in the field ($H = 5$) were involved to such an aim, whose roles are given in Table 3.

Table 3. Roles of the decision makers.

Decision Maker	Role
H_1	Maintenance responsible
H_2	Quality manager
H_3	Consultant
H_4	Chief of the safety and security system
H_5	Department chief

The experts composing the decision-making group contribute to the process development by playing diverse, but complementary, roles. Indeed, these subjects have been involved with the aim of guaranteeing as complete as possible understanding about the problem under analysis.

Each decision-maker was asked to evaluate the direct influence between any two human factors by means of integer scores from 0 to 4. Five non-negative square matrices $X^{(1)}$, $X^{(2)}$, $X^{(3)}$, $X^{(4)}$ and $X^{(5)}$ (given in the Appendix A) were collected and then aggregated to obtain the direct-relation matrix A of order 16 (Table 4).

Tables 5 and 6 respectively show the normalized direct-relation matrix D and the total relation matrix T. Lastly, Table 7 shows the values of $r_i + c_i$ and $r_i - c_i$ associated to the various factors, and the ranking of factors, obtained on the basis of their prominence, $r_i + c_i$, which collects the direct and indirect effects related to all the other factors.

Table 4. Direct-relation matrix *A*.

A	HF_1	HF_2	HF_3	HF_4	HF_5	HF_6	HF_7	HF_8	HF_9	HF_{10}	HF_{11}	HF_{12}	HF_{13}	HF_{14}	HF_{15}	HF_{16}
HF_1	0.000	3.200	1.800	1.600	4.000	2.000	2.400	2.200	4.000	3.600	4.000	4.000	1.800	2.800	4.000	2.200
HF_2	2.200	0.000	2.800	3.000	2.600	0.000	0.000	3.200	1.200	1.600	1.600	1.200	0.000	0.000	2.600	1.400
HF_3	2.200	2.000	0.000	4.000	3.000	3.000	3.000	3.000	0.000	0.000	0.000	0.000	0.000	0.000	1.800	1.600
HF_4	2.000	3.200	3.200	0.000	4.000	1.200	4.000	3.200	0.000	0.000	0.000	0.000	2.400	1.200	3.600	3.600
HF_5	3.600	2.000	3.200	4.000	0.000	2.800	2.800	2.800	2.400	2.800	2.400	2.800	1.200	4.000	4.000	2.400
HF_6	2.400	1.000	2.200	2.400	3.200	0.000	2.000	3.400	1.400	1.400	1.400	1.400	4.000	2.800	3.000	3.800
HF_7	1.400	0.000	2.200	2.600	3.200	3.000	0.000	4.000	1.600	1.600	1.600	1.600	3.200	0.000	2.200	4.000
HF_8	2.600	2.200	3.000	3.000	3.600	2.400	4.000	0.000	1.800	1.800	1.800	1.800	2.400	2.200	3.200	2.000
HF_9	4.000	1.200	0.000	0.000	2.800	1.400	2.000	1.800	0.000	0.200	0.200	0.200	3.000	1.400	3.200	1.800
HF_{10}	4.000	1.200	0.000	0.000	2.800	1.400	2.000	1.800	0.200	0.000	0.200	0.200	2.600	1.000	2.800	1.800
HF_{11}	4.000	1.200	0.000	0.000	2.800	1.400	2.000	1.800	0.200	0.200	0.000	0.200	2.600	1.400	2.200	1.800
HF_{12}	4.000	1.200	0.000	0.000	2.800	1.400	2.000	1.800	0.200	0.200	0.200	0.000	3.000	1.000	3.200	3.000
HF_{13}	1.800	0.000	0.000	2.200	1.400	4.000	3.200	2.000	3.000	3.000	3.000	3.000	0.000	3.200	3.800	3.800
HF_{14}	4.000	0.000	0.000	1.000	3.000	2.800	0.000	2.200	1.000	1.000	1.600	1.000	3.600	0.000	3.200	2.200
HF_{15}	4.000	2.200	1.400	4.000	3.600	3.000	2.200	3.200	2.200	3.200	1.800	1.200	3.400	3.200	0.000	3.200
HF_{16}	3.600	2.000	1.200	4.000	2.000	3.400	3.000	2.000	1.800	2.800	1.800	2.000	3.600	1.800	2.000	0.000

Table 5. Normalised direct-relation matrix *D*.

D	HF_1	HF_2	HF_3	HF_4	HF_5	HF_6	HF_7	HF_8	HF_9	HF_{10}	HF_{11}	HF_{12}	HF_{13}	HF_{14}	HF_{15}	HF_{16}
HF_1	0.000	0.070	0.039	0.035	0.087	0.044	0.052	0.048	0.087	0.079	0.087	0.087	0.039	0.061	0.087	0.048
HF_2	0.048	0.000	0.061	0.066	0.057	0.000	0.000	0.070	0.026	0.035	0.035	0.026	0.000	0.000	0.057	0.031
HF_3	0.048	0.044	0.000	0.087	0.066	0.066	0.066	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.039	0.035
HF_4	0.044	0.070	0.070	0.000	0.087	0.026	0.087	0.070	0.000	0.000	0.000	0.000	0.052	0.026	0.079	0.079
HF_5	0.079	0.044	0.070	0.087	0.000	0.061	0.061	0.061	0.052	0.061	0.052	0.061	0.026	0.087	0.087	0.052
HF_6	0.052	0.022	0.048	0.052	0.070	0.000	0.044	0.074	0.031	0.031	0.031	0.031	0.087	0.061	0.066	0.083
HF_7	0.031	0.000	0.048	0.057	0.070	0.066	0.000	0.087	0.035	0.035	0.035	0.035	0.070	0.000	0.048	0.087
HF_8	0.057	0.048	0.066	0.066	0.079	0.052	0.087	0.000	0.039	0.039	0.039	0.039	0.052	0.048	0.070	0.044
HF_9	0.087	0.026	0.000	0.000	0.061	0.031	0.044	0.039	0.000	0.004	0.004	0.004	0.066	0.031	0.070	0.039
HF_{10}	0.087	0.026	0.000	0.000	0.061	0.031	0.044	0.039	0.004	0.000	0.004	0.004	0.057	0.022	0.061	0.039
HF_{11}	0.087	0.026	0.000	0.000	0.061	0.031	0.044	0.039	0.004	0.004	0.000	0.004	0.057	0.031	0.048	0.039
HF_{12}	0.087	0.026	0.000	0.000	0.061	0.031	0.044	0.039	0.004	0.004	0.004	0.000	0.066	0.022	0.070	0.066
HF_{13}	0.039	0.000	0.000	0.048	0.031	0.087	0.070	0.044	0.066	0.066	0.066	0.066	0.000	0.070	0.083	0.083
HF_{14}	0.087	0.000	0.000	0.022	0.066	0.061	0.000	0.048	0.022	0.022	0.035	0.022	0.079	0.000	0.070	0.048
HF_{15}	0.087	0.048	0.031	0.087	0.079	0.066	0.048	0.070	0.048	0.070	0.039	0.026	0.074	0.070	0.000	0.070
HF_{16}	0.079	0.044	0.026	0.087	0.044	0.074	0.066	0.044	0.039	0.061	0.039	0.044	0.079	0.039	0.044	0.000

Table 6. Total direct-relation matrix T.

T	HF_1	HF_2	HF_3	HF_4	HF_5	HF_6	HF_7	HF_8	HF_9	HF_{10}	HF_{11}	HF_{12}	HF_{13}	HF_{14}	HF_{15}	HF_{16}
HF_1	0.209	0.175	0.140	0.186	0.285	0.198	0.211	0.221	0.190	0.195	0.192	0.187	0.209	0.190	0.287	0.224
HF_2	0.162	0.068	0.123	0.155	0.172	0.090	0.098	0.167	0.086	0.102	0.095	0.085	0.094	0.076	0.171	0.129
HF_3	0.164	0.113	0.075	0.186	0.188	0.157	0.165	0.174	0.067	0.075	0.068	0.066	0.102	0.081	0.162	0.145
HF_4	0.199	0.155	0.158	0.137	0.243	0.155	0.214	0.210	0.090	0.102	0.091	0.088	0.181	0.130	0.235	0.217
HF_5	0.281	0.154	0.173	0.240	0.208	0.218	0.223	0.237	0.158	0.179	0.160	0.164	0.199	0.214	0.289	0.232
HF_6	0.228	0.117	0.139	0.191	0.243	0.144	0.188	0.224	0.128	0.139	0.129	0.126	0.233	0.177	0.242	0.237
HF_7	0.191	0.090	0.132	0.183	0.227	0.192	0.137	0.222	0.122	0.132	0.122	0.120	0.203	0.109	0.209	0.227
HF_8	0.236	0.145	0.160	0.207	0.258	0.194	0.231	0.162	0.136	0.148	0.138	0.134	0.202	0.164	0.251	0.206
HF_9	0.205	0.092	0.066	0.099	0.181	0.129	0.141	0.145	0.074	0.086	0.079	0.076	0.167	0.116	0.193	0.148
HF_{10}	0.199	0.089	0.063	0.095	0.175	0.124	0.136	0.140	0.075	0.078	0.075	0.073	0.153	0.103	0.178	0.142
HF_{11}	0.197	0.088	0.062	0.093	0.173	0.122	0.135	0.138	0.074	0.081	0.070	0.072	0.151	0.110	0.164	0.141
HF_{12}	0.210	0.095	0.068	0.104	0.185	0.133	0.146	0.149	0.081	0.090	0.082	0.075	0.171	0.110	0.197	0.177
HF_{13}	0.223	0.096	0.090	0.180	0.210	0.225	0.211	0.197	0.159	0.171	0.160	0.156	0.161	0.186	0.260	0.240
HF_{14}	0.223	0.077	0.072	0.130	0.201	0.170	0.116	0.165	0.103	0.111	0.116	0.101	0.194	0.099	0.210	0.171
HF_{15}	0.285	0.157	0.137	0.239	0.278	0.221	0.211	0.242	0.157	0.190	0.151	0.134	0.241	0.201	0.208	0.246
HF_{16}	0.252	0.139	0.120	0.219	0.222	0.210	0.208	0.199	0.135	0.166	0.137	0.137	0.226	0.155	0.225	0.162

Table 7. Final ranking.

	$r_i + c_i$	$r_i - c_i$	Ranking	$r_i + c_i \cdots \downarrow$
HF_1	6.762	−0.167	HF_5	6.779
HF_2	3.721	0.024	HF_{15}	6.776
HF_3	3.765	0.210	HF_1	6.762
HF_4	5.250	−0.037	HF_8	5.964
HF_5	6.779	−0.121	HF_{16}	5.954
HF_6	5.568	0.202	HF_{13}	5.809
HF_7	5.390	−0.152	HF_6	5.568
HF_8	5.964	−0.020	HF_7	5.390
HF_9	3.833	0.162	HF_4	5.250
HF_{10}	3.943	−0.148	HF_{14}	4.477
HF_{11}	3.733	0.006	HF_{10}	3.943
HF_{12}	3.866	0.276	HF_{12}	3.866
HF_{13}	5.809	0.039	HF_9	3.833
HF_{14}	4.477	0.040	HF_3	3.765
HF_{15}	6.776	−0.181	HF_{11}	3.733
HF_{16}	5.954	−0.133	HF_2	3.721

Human factors with higher $r_i + c_i$ value, as explained in step 6 before, give crucial information regarding, in our case, how to reduce organisational risk, since their variations have greater impact on the variations of all the other aspects. As explained in step 7, a threshold has to be established for not taking into account negligible effects. As said, this threshold is here calculated as the average of all the elements in matrix T. In this case the threshold is 0.159. Now, those factors having a value of $T(\mathrm{HF}_i; \mathrm{HF}_i)$ higher than the threshold are selected.

Accordingly, we suggest that the human factors occupying the first six positions of the ranking need to be more carefully monitored during the process of organisational risk management. They are, in order:

- **HF$_5$**: Reward systems related to the achievement of security objectives are not defined;
- **HF$_{15}$**: Workers lead tasks having high level of responsibility for stakeholders, plants and production;
- **HF$_1$**: System of security and safety management not implemented;
- **HF$_8$**: Rigid protocols supervising and controlling workers are implemented;
- **HF$_{16}$**: Shifts may be not well organised;
- **HF$_{13}$**: Unpredictably variations of workload.

Figure 3 presents the four quadrants of the chart derived from the DEMATEL application. From this representation, decision makers can visually identify causal relationships among the considered human factors. The rationale for selecting, Si et al. [42], may be summarized as follows:

- Factors in quadrant I are identified as core factors or intertwined givers since they have high prominence and relation;
- Factors in quadrant II have low prominence but high relation, which are impacted by other factors and cannot be directly improved;
- Factors in quadrant III have low prominence and relation and are relatively disconnected from the system;
- Factors in quadrant IV are identified as driving factors or autonomous givers because they have high prominence but low relation.

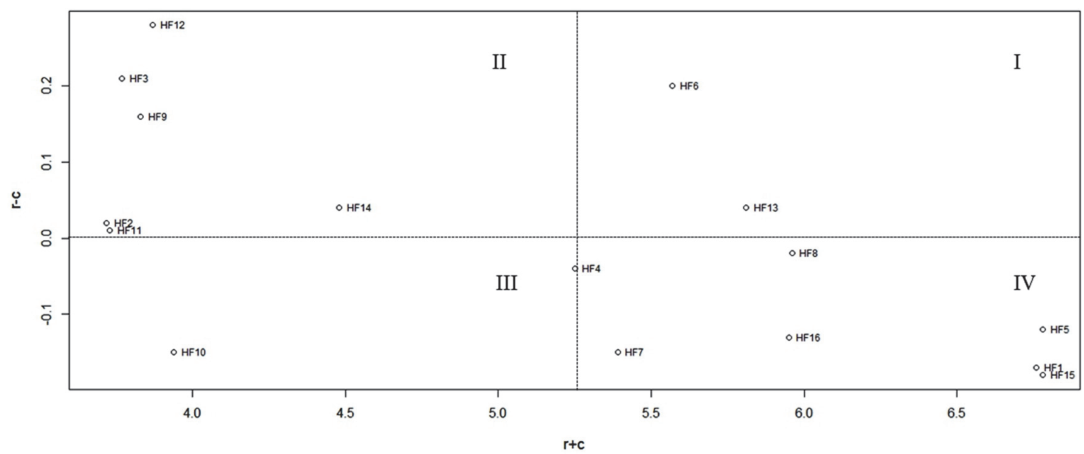

Figure 3. Decision-making trial and evaluation laboratory (DEMATEL) chart with human factors (HFs) spread out into quadrants.

Figure 4 shows the interdependencies among the selected HFs, the casual factors. In this methodology, arrows for the factors with values $T(\mathrm{HF}_i; \mathrm{HF}_i)$ lower than this threshold are not customary indicated in the graph, meaning that the corresponding interdependencies can be neglected [43]. The relations corresponding to the ten unselected HFs are, thus, not represented for the sake of clarity, despite some relation of interdependence between them and the other factors may exist.

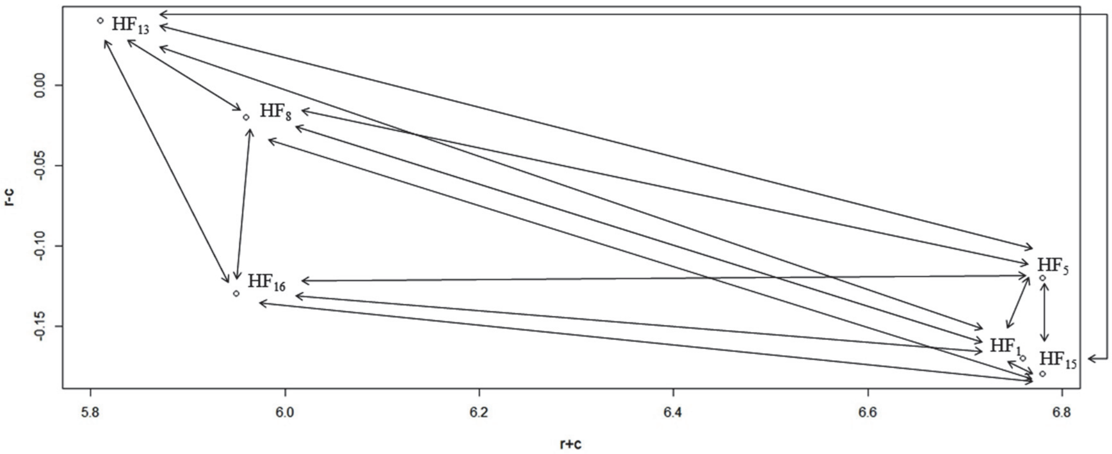

Figure 4. Chart representing interdependencies among the six selected HFs.

By analysing the six selected human factors, we can observe that human factor HF_5, by occupying the first position of the ranking, reveals the need for better defining reward systems related to the achievement of security objectives. This could be pursued by motivating workers in actively participating to the implementation of a system of security and safety management, as suggested also by human factor HF_1. Thus, this implementation may simultaneously enhance these two factors and can be addressed by starting from a clearer definition of procedures related to the planning and execution of preventive maintenance intervention for the bottling plant. Moreover, three of the selected factors (HF_{15}, HF_{16}, HF_{13}) belong to area A_8 (see Table 2), that is, "Workload and working hours". It means that, for example, interventions aimed at rearranging aspects related to the entity of workload and the number of working hours per worker could help improve the entire process under the organisational point of view.

Lastly, let us underline that, among the six selected HFs, the value of the difference $(r_i - c_i)$ is positive just for HF_{13}, what makes this factor a possible cause of bad process organisation and its improvement will produce benefits. The other five factors have associated a negative value of difference $(r_i - c_i)$, so these factors must be interpreted as cause factors of perceived risk.

5. Conclusions

The present paper deals with organisational risk assessment in industry, a field in which the role of human factors is crucial. In particular, a MCDM approach based on the DEMATEL methodology has been proposed to evaluate interdependencies among critical human factors. This method enables to rank human factors so that a framework for prioritising interventions thus reducing risk is suggested. From the influential relation map pictured in the chart, decision makers can visually detect the complex causal relationships among factors and highlight further valuable insights for decision-making.

The proposed approach is applied to a real-world case study related to a winery located in Sicily (Italy). The process of wine bottling has been taken into account, and results coming from a previous organisational risk evaluation have been manipulated. This evaluation highlighted 16 critical human factors with relation to the group of workers distributed in the analysed working area. The DEMATEL has been used to rank human factors on the basis of their interdependencies. The selected human factors (namely HF_5, HF_{15}, HF_1, HF_8, HF_{16}, HF_{13}) give fundamental information, and their variations correspond to variations of all the other aspects. For this reason, these human factors need to be monitored with priority during the process of organisational risk management.

Since the human factor HF_5 occupies the first position in the ranking, the company should consider as primary action the definition of reward systems related to the achievement of security objectives. This may be undertaken by motivating workers in taking part in the implementation of a system of security and safety management starting from a clearer definition of procedures related to the planning and execution of preventive maintenance intervention for the bottling plant. In this way, HF5 and HF1 would be simultaneously taken into account. This aspect may be further investigated, also in terms of management of the maintenance monitoring process, through suitable key performance indices, and the practical validity of our proposal should be carefully tested once the actions we suggest will be implemented in the context of reference.

Moreover, this work may be further extended by means of other MCDM approaches to support, and to the practical implementation of measures aimed at reducing organisational risk. These measures and their planning would directly derive from the ranking achieved in the present research. For example, the fuzzy set theory could be a useful tool to manage uncertainty and vagueness of the involved experts. In particular, with special regard to the critical human factors highlighted in the present article, an inference engine may be developed to support risk management. As another example, the analytic hierarchy process (AHP) method can also be employed to find out the weights of factors/aspects and obtain suitable scores for various actions that could be implemented. Lastly, the analytic hierarchy process (ANP), as an extension of the AHP, can be applied with the aim of understanding more complex dependency relationships among criteria.

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Appendix A

Table A1. Non-negative matrix $X^{(1)}$ filled in by the expert H_1, "maintenance responsible".

X^1	HF_1	HF_2	HF_3	HF_4	HF_5	HF_6	HF_7	HF_8	HF_9	HF_{10}	HF_{11}	HF_{12}	HF_{13}	HF_{14}	HF_{15}	HF_{16}
HF_1	0	3	1	1	4	2	2	2	4	4	4	4	1	3	4	2
HF_2	2	0	3	3	3	0	0	3	1	1	1	1	0	0	2	1
HF_3	2	2	0	4	3	3	3	3	0	0	0	0	0	0	2	2
HF_4	2	3	3	0	4	1	4	3	0	0	0	0	2	1	4	4
HF_5	4	2	3	4	0	3	3	3	3	3	3	3	1	4	4	2
HF_6	2	1	2	2	3	0	2	3	1	1	1	1	4	3	3	4
HF_7	1	0	2	3	3	3	0	4	2	2	2	2	3	0	2	4
HF_8	2	2	3	3	4	2	4	0	2	2	2	2	2	2	3	2
HF_9	4	1	0	0	3	1	2	2	0	0	0	0	3	1	3	2
HF_{10}	4	1	0	0	3	1	2	2	0	0	0	0	3	1	3	2
HF_{11}	4	1	0	0	3	1	2	2	0	0	0	0	3	1	2	2
HF_{12}	4	1	0	0	3	1	2	2	0	0	0	0	3	1	3	3
HF_{13}	1	0	0	2	1	4	3	2	3	3	3	3	0	3	4	4
HF_{14}	4	0	0	1	3	3	0	2	1	1	2	1	4	0	3	2
HF_{15}	4	2	1	4	4	3	2	3	2	3	2	1	4	3	0	3
HF_{16}	3	2	1	4	2	4	3	2	2	3	2	2	4	2	2	0

Table A2. Non-negative matrix $X^{(2)}$ filled in by the expert H_2, "quality manager".

X^2	**HF$_1$**	**HF$_2$**	**HF$_3$**	**HF$_4$**	**HF$_5$**	**HF$_6$**	**HF$_7$**	**HF$_8$**	**HF$_9$**	**HF$_{10}$**	**HF$_{11}$**	**HF$_{12}$**	**HF$_{13}$**	**HF$_{14}$**	**HF$_{15}$**	**HF$_{16}$**
HF$_1$	0	3	2	2	4	1	2	1	4	3	4	4	2	2	4	2
HF$_2$	2	0	2	3	2	0	0	3	1	2	2	1	0	0	3	2
HF$_3$	2	2	0	4	3	3	3	3	0	0	0	0	0	0	1	1
HF$_4$	1	3	3	0	4	1	4	3	0	0	0	0	2	1	3	3
HF$_5$	3	2	3	4	0	3	3	3	2	3	2	3	1	4	4	3
HF$_6$	2	1	2	3	4	0	2	3	1	1	1	1	4	3	3	4
HF$_7$	1	0	2	2	4	3	0	4	1	1	1	1	3	0	2	4
HF$_8$	2	2	3	2	4	2	4	0	1	1	1	1	2	2	3	2
HF$_9$	4	1	0	0	3	1	2	1	0	0	0	0	3	2	3	2
HF$_{10}$	4	1	0	0	3	1	2	1	0	0	0	0	2	1	2	2
HF$_{11}$	4	1	0	0	3	1	2	1	0	0	0	0	2	2	2	2
HF$_{12}$	4	1	0	0	3	1	2	1	0	0	0	0	3	1	3	3
HF$_{13}$	2	0	0	2	1	4	3	1	3	3	3	3	0	3	4	3
HF$_{14}$	4	0	0	1	3	3	0	2	1	1	1	1	4	0	3	2
HF$_{15}$	4	2	1	4	3	3	2	3	2	3	1	1	4	3	0	3
HF$_{16}$	4	2	1	4	2	3	3	2	2	3	2	2	4	2	2	0

Table A3. Non-negative matrix $X^{(3)}$ filled in by the expert H_3, "consultant".

X^3	**HF$_1$**	**HF$_2$**	**HF$_3$**	**HF$_4$**	**HF$_5$**	**HF$_6$**	**HF$_7$**	**HF$_8$**	**HF$_9$**	**HF$_{10}$**	**HF$_{11}$**	**HF$_{12}$**	**HF$_{13}$**	**HF$_{14}$**	**HF$_{15}$**	**HF$_{16}$**
HF$_1$	0	3	1	1	4	3	3	3	4	4	4	4	1	3	4	2
HF$_2$	2	0	3	3	3	0	0	3	2	2	2	2	0	0	2	1
HF$_3$	2	2	0	4	3	3	3	3	0	0	0	0	0	0	2	2
HF$_4$	2	3	3	0	4	1	4	3	0	0	0	0	2	1	4	4
HF$_5$	4	2	3	4	0	2	2	2	2	2	2	2	1	4	4	2
HF$_6$	3	1	2	2	2	0	2	3	1	1	1	1	4	3	3	4
HF$_7$	2	0	2	3	2	3	0	4	2	2	2	2	3	0	2	4
HF$_8$	3	2	3	3	3	2	4	0	2	2	2	2	2	2	3	2
HF$_9$	4	2	0	0	2	1	2	2	0	0	0	0	2	1	3	2
HF$_{10}$	4	2	0	0	2	1	2	2	0	0	0	0	2	1	3	2
HF$_{11}$	4	2	0	0	2	1	2	2	0	0	0	0	2	1	2	2
HF$_{12}$	4	2	0	0	2	1	2	2	0	0	0	0	2	1	3	3
HF$_{13}$	1	0	0	2	2	4	3	2	2	2	2	2	0	3	4	4
HF$_{14}$	4	0	0	1	3	3	0	2	1	1	2	1	3	0	3	3
HF$_{15}$	4	2	1	4	4	3	2	3	2	3	2	1	3	3	0	3
HF$_{16}$	3	2	1	4	2	4	3	2	2	3	2	2	3	1	1	0

Table A4. Non-negative matrix $X^{(4)}$ filled in by the expert H_4, "chief of the safety and security system".

X^4	**HF$_1$**	**HF$_2$**	**HF$_3$**	**HF$_4$**	**HF$_5$**	**HF$_6$**	**HF$_7$**	**HF$_8$**	**HF$_9$**	**HF$_{10}$**	**HF$_{11}$**	**HF$_{12}$**	**HF$_{13}$**	**HF$_{14}$**	**HF$_{15}$**	**HF$_{16}$**
HF$_1$	0	3	2	2	4	1	2	1	4	3	4	4	2	2	4	2
HF$_2$	2	0	2	3	2	0	0	3	1	2	2	1	0	0	3	2
HF$_3$	2	2	0	4	3	3	3	2	0	0	0	0	0	0	1	1
HF$_4$	1	3	3	0	4	1	4	3	0	0	0	0	2	1	3	3
HF$_5$	3	2	3	4	0	3	3	2	2	3	2	3	1	4	4	3
HF$_6$	2	1	2	3	4	0	2	4	3	3	3	3	4	2	2	3
HF$_7$	1	0	2	2	4	3	0	4	1	1	1	1	3	0	2	4
HF$_8$	2	2	2	3	3	3	4	0	1	1	1	1	2	2	3	1
HF$_9$	4	1	0	0	3	3	2	1	0	1	1	1	3	2	3	1
HF$_{10}$	4	1	0	0	3	3	2	1	1	0	1	1	2	1	2	1
HF$_{11}$	4	1	0	0	3	3	2	1	1	1	0	1	2	2	2	1
HF$_{12}$	4	1	0	0	3	3	2	1	1	1	1	0	3	1	3	3
HF$_{13}$	2	0	0	2	1	4	3	1	3	3	3	3	0	3	3	4
HF$_{14}$	4	0	0	1	3	2	0	2	1	1	1	1	3	0	3	2
HF$_{15}$	4	2	1	4	3	2	2	3	2	3	1	1	2	3	0	3
HF$_{16}$	4	2	1	4	2	2	3	1	1	2	1	2	3	2	2	0

Table A5. Non-negative matrix $X^{(5)}$ filled in by the expert H_5, "Department chief".

X^5	**HF$_1$**	**HF$_2$**	**HF$_3$**	**HF$_4$**	**HF$_5$**	**HF$_6$**	**HF$_7$**	**HF$_8$**	**HF$_9$**	**HF$_{10}$**	**HF$_{11}$**	**HF$_{12}$**	**HF$_{13}$**	**HF$_{14}$**	**HF$_{15}$**	**HF$_{16}$**
HF$_1$	0	4	3	2	4	3	3	4	4	4	4	4	3	4	4	3
HF$_2$	3	0	4	3	3	0	0	4	1	1	1	1	0	0	3	1
HF$_3$	3	2	0	4	3	3	3	4	0	0	0	0	0	0	3	2
HF$_4$	4	4	4	0	4	2	4	4	0	0	0	0	4	2	4	4
HF$_5$	4	2	4	4	0	3	3	4	3	3	3	3	2	4	4	2
HF$_6$	3	1	3	2	3	0	2	4	1	1	1	1	4	3	4	4
HF$_7$	2	0	3	3	3	3	0	4	2	2	2	2	4	0	3	4
HF$_8$	4	3	4	4	4	3	4	0	3	3	3	3	4	3	4	3
HF$_9$	4	1	0	0	3	1	2	3	0	0	0	0	4	1	4	2
HF$_{10}$	4	1	0	0	3	1	2	3	0	0	0	0	4	1	4	2
HF$_{11}$	4	1	0	0	3	1	2	3	0	0	0	0	4	1	3	2
HF$_{12}$	4	1	0	0	3	1	2	3	0	0	0	0	4	1	4	3
HF$_{13}$	3	0	0	3	2	4	4	4	4	4	4	4	0	4	4	4
HF$_{14}$	4	0	0	1	3	3	0	3	1	1	2	1	4	0	4	2
HF$_{15}$	4	3	3	4	4	4	3	4	3	4	3	2	4	4	0	4
HF$_{16}$	4	2	2	4	2	4	3	3	2	3	2	2	4	2	3	0

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