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Preference-Based Assessment of Organisational Risk in Complex Environments

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Abstract. This paper proposes a preference-based approach for optimising the process of organisational risk assessment in complex and uncertain environments, where significant decision-making factors may be interconnected. Organisational risks are herein treated from the perspective of the work-related stress risk involving psycho-physical factors crucial for the safety and well-being of human resources. The traditional Health and Safety Executive (HSE) model commonly used for stress evaluation in working environments is herein improved by first applying the Analytic Network Process (ANP) to weight management standards (MS). This technique has been chosen to avoid neglecting potential relations bounding MS with each other. Finally, Fuzzy Cognitive Maps (FCMs) are used to study dependence among significant stress factors. In such a direction, the support offered by the fuzzy set theory is relevant to deal with subjective evaluations of preference. The case of an Italian airport is analysed to demonstrate the applicability of the approach, and managerial insights are discussed.

Keywords: Organisational risk · Decision-making · Analytic Network Process · Fuzzy Cognitive Maps · Complexity management

1 Motivation and State of the Art

The occurrence of organisational risks may have a strong impact on human resources' safety. This category of risks is related to organisational shortcomings and includes work-related stress as well as psychological factors as fundamental elements of analysis. Specifically, not only are psychological factors crucial for human well-being and professional achievement but also hugely influence operational performance by contributing to generating company results on the whole [7]. Increasing attention is devoted nowadays to research on psychological factors within entrepreneurial realities. In this context, proper assessments

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of the risk of work-related stress greatly contribute to approaching and better understanding how to manage these types of factors. The existence of particular indicators is investigated, as well as work conditions that may cause discomfort and stress for workers, leading to their poor performance and dissatisfaction.

The risk of work-related stress is commonly assessed by preliminary analysing such conditions as professional environment, working hours, monotony or fragmentation of tasks, uncertainty, excessive or insufficient workload, relationships among colleagues and superiors, and so on [9]. These factors could potentially harm the psycho-physical health of workers, especially if they have to act in synergy with each other. In any case, evidence demonstrates that they coexist in almost any work environment, reducing organisational effectiveness. This is the reason why work-related stress risk assessment has to be implemented by companies, as established by the existing international standards.

Among the various methodologies used to purse such a type of evaluation [10,15], we here discuss the integrated management approach developed by the British agency Health and Safety Executive (HSE). The evaluation model applies the perspective of Research & Development activities, aiming at scientifically demonstrating the entity of repercussions of work-related stress on general health conditions of individuals. The HSE model analyses six main areas or management standards (MS), by proposing a structured interview to workers in the form of an inquiring questionnaire tool called the MS indicator tool [8]. Each item of the questionnaire refers to a specific MS. The goal consists in investigating critical organisational aspects to be improved by contributing to the creation of a research network system in the field of occupational health and safety. Specifically, the HSE indicator tool is specially focused on physical and psychical consequences as well as progressive alterations of lifestyle and behavior of workers. Given the huge complexity and the uncertainty characterising this field, the present paper proposes a methodological framework by combining the Analytic Network Process (ANP), a well-known decision-making technique, with the *ah hoc* generation of Fuzzy Cognitive Maps (FCMs), the latter being particularly suitable for managing uncertainty when subjective preference evaluations are required [3]. As an artificial intelligence technique capable of effectively supporting decision-making [1], FCM integrates characteristics of fuzzy sets and neural networks. As reported by López and Ishizaka [6], FCMs have been successfully hybridized with several multi-criteria decision-making techniques so far. In particular, by mentioning a work of research specifically integrating ANP and FCM [14], the authors underline as FCMs ,ay support in the calculation of local and/or global weights of a set of decision-making elements. Considering this evidence, we aim to exploit the strengths derived from such a methodological integration. To the best of the authors' knowledge, it is the first time that ANP and FCMs are combined for improving the process of organisational risk management in terms of work-related stress assessment.

With these preliminaries, the six MS considered by the HSE model will be first analysed and their mutual importance will be established by means of the ANP. Second, a suitable FCM will be built to study relations of dependence bounding the main aspects investigated by the HSE indicator tool. This integration can positively contribute to the topic of research by effectively highlighting critical issues so that possibilities of improvement of working conditions in complex environment can be real.

The research is organised as follows. Traditional HSE methodology is discussed in Sect. 2, where the items of the indicator tool are associated to the corresponding MS. Section 3 provides methodological details about the preference-based approach. An Italian airport has been analysed for the real application of Sect. 4, airports being extremely complex organisations where many stressful factors may likely impact on employees conditions. Conclusions of Sect. 5 close the paper by discussing potential future developments.

2 HSE Management Standards for Organisational Risks

MS may be classified according to three organisational dimensions: 1. **content** (cnt), referring to general pressures workers may feel because of work characteristics, 2. **context** (cxt), referring to work environment, human relations and cooperation, 3. **awareness** (aws), referring to the personal perception of workers about their own contribution and involvement. Within these three main dimension groups, six MS are identified as key areas that, when not properly managed, are associated with health problems and lower productivity as well as increasing probability of injuries and rates of sickness absence.

- MS_1, demand: it includes such aspects as workload, tasks and environment;
- MS_2, control: it refers to autonomy of people in the way they lead their job;
- MS_3, support, it includes encouragement and resources from the company;
- MS_4, relationship, it refers to managing conflict and unacceptable behaviour;
- MS_5, role, it considers the clear understanding about specific working roles;
- MS_6, change, it refers to change management and communication processes.

Specifically, MS_1 and MS_2 belong to the content dimension, MS_3 and MS_4 refer to the context dimension, while MS_5 and MS_6 are related to the awareness dimension. The interesting idea behind MS-based approach is that companies have the possibility of benchmarking their current practices of organisational risk evaluation by designing related measures to enhance stress management performance. The HSE indicator tool aims to support this process. Thirty-five items are randomly proposed to workers and the related answers can be provided according to a linguistic scale. Analysing the questionnaire from a structural point of view, that is to say, by connecting specific items to MS, is useful to further elaborate employees' responses. This classification will help to easily understand if the standards are achieved or not. In such a direction, Table 1 organises the items of the questionnaire by associating them to the corresponding MS to ease the evaluation of the most critical area(s).

The HSE model based on the six described MS can be hence considered as an integrated approach to design and optimise the simultaneous management of stressful factors, usually interacting with each other in real contexts. Such an interaction would lead to the amplification of the effects that these factors

Table 1. Decision-making elements under analysis

ID	MS	Items of management standard indicator tool
MS_1	Demand	DE_1 I clearly understand the expectations about my work
		DE_2 I do not experience difficulties when I have to combine job requests coming from diverse people and/or operational units
		DE_3 I know how to perform my job and all the related tasks
		DE_4 I usually have deadlines not extremely difficult to meet
		DE_5 I do not have to perform particularly hard activities
		DE_6 I do not neglect private issues because of my work
		DE_7 I do not feel high pressure due to overtime work
		DE_8 I do not have to be very quick when leading operations
		DE_9 I never fail in satisfactorily meeting my deadlines
MS_2	Control	CO_1 I can autonomously decide when to have a break
		CO_2 I can decide the rhythm at which my tasks are performed
		CO_3 I can make decisions about the organisation of my work
		CO_4 I am free to take enough breaks
		CO_5 I have freedom of choice about the content of my tasks
		CO_6 I can express my opinions about how to perform my tasks
		CO_7 I have flexible working hours
MS_3	Support	SU_1 I am supported by my colleagues for difficult work
		SU_2 I receive effective information that is helpful for my activity
		SU_3 I can rely on my boss should I experience any problem
		SU_4 I receive the help and support I need from colleagues
		SU_5 I can openly discuss with my boss if I am annoyed
		SU_6 I use to dialogue with my colleagues about my problems
		SU_7 I am supported in emotionally demanding tasks
		SU_8 I often receive encouragement by my boss
MS_4	Relationship	RE_1 I do not experience personal harassment in the form of rude words or bad behavior from other colleagues and/or superiors
		RE_2 Frictions or conflicts among colleagues are rare
		RE_3 I am not bullied nor subjected to any restriction
		RE_4 I have the respect that I deserve from my colleagues
		RE_5 Relationships in my workplace are not strained
MS_5	Role	RO_1 I have clear my duties and responsibilities
		RO_2 I have clear the objectives and goals of my department
		RO_3 I have a clear understanding about the importance of my work in pursuing the overall goals of the organization
MS_6	Change	CH_1 I have sufficient opportunities to ask managers for explanations about any change related to my work
		CH_2 Staff is always consulted about potential changes
		CH_3 I clearly understand the practical effects of those changes happening in my work environment

would have if they were isolated. Getting a comprehensive knowledge about MS is essential to lead the risk assessment process according to the particular characteristics of the organisation under analysis.

3 Methodological Approach

In this section we provide methodological details of the techniques we are going to integrate for supporting procedures of organisational risk assessment. The purpose consists in providing a scientifically sound support for dealing with complex environments, where elements of evaluation are typically highly interconnected, and quantitative assessments of variables may be difficult.

The ANP will attribute degrees of importance to MS by taking into account the existence of complex relations of mutual dependence. FCMs will help to understand which items - among those belonging to the mainly critical WS - are the most significant to promote proper management actions.

3.1 ANP to Weight Management Standards

The ANP, first implemented by Thomas Saaty [13] as a development of the Analytic Hierarchy Process (AHP) [12], is a decision-making tool widely applied to assess the main elements of a problem (also called nodes). The goal consists in calculating a vector of weights by considering the possible interdependence among the nodes. In the present paper, the ANP application is conducted to evaluate the set of six MS discussed in the previous section. The practical application will be led by collecting preference judgments with the help of an expert in the field. The ANP technique is implemented as described next [4].

- Representing the decision-making problem by means of a hierarchical structure, clearly characterising nodes. Once the structure has been fixed, relations of interdependence among the nodes have to be formalised. At this stage, opinions provided by the expert will be important to highlight and characterise any possible relation.
- Building the influence matrix, in which relations identified during the previous stage are formalised. The influence matrix is a squared block matrix, whose size equals the total number of nodes and whose entries a_{ij} are equal to 1 if a relation of dependence between element j over element i exists, 0 otherwise. The influence matrix acts as a template for the non-zero elements of the unweighted supermatrix described next.
- Building the unweighted supermatrix (following the non-zero-entry structure of the influence matrix) by pairwise comparing those nodes for which a relation of dependence has been identified ($a_{ij} = 1$), and by calculating weights for the corresponding elements, for example by making use of the AHP, as we will propose in our application. The calculated weights will be the entries of the unweighted supermatrix.
- Producing the weighted supermatrix by means of a normalisation procedure. The sums of the columns of the weighted supermatrix will be equal to one and, in such a way, the matrix gets stochastic.
- Obtaining the limit matrix by raising to powers the weighted supermatrix. All the columns of the limit matrix are equal, and each one of them represents the global priorities, which will have to be eventually normalised to produce the sought information.

- Formalising the final vectors of weights, which embody the interdependence accumulated throughout the successive powering of the weighted supermatrix. Broadly speaking, elements with associated higher values should have major prominence in leading the decision-making process.

3.2 FCM for Analysing Dependence Relations

FCMs [5] enables to analyse complex decision-making problems by modelling and understanding relationships of dependence coexisting within a set of elements [2]. Relations are represented by means of linguistic variables treated as fuzzy numbers. Indirect effects and total effects (namely IE and TE) from element C_i to element C_j are described by using such linguistic evaluations e_{ij} as *much*, *some* and *a lot*, to be translated to fuzzy numbers. Figure 1 shows as an example the FCM proposed in [5], whose network is used to formalise the next equations.

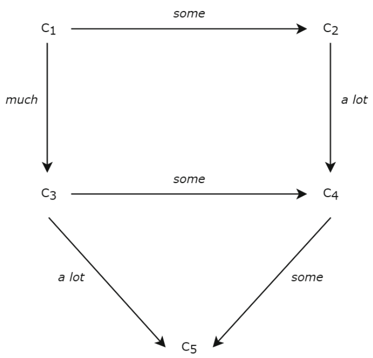

Fig. 1. Example of FCM developed by Kosko [5]

C_1 and C_5 can be connected with each other by means of three possible casual paths, which we herein indicate as $P_1(1-2-4-5)$, $P_2(1-3-5)$ and $P_3(1-3-4-5)$. Tree indirect effects between C_1 and C_5 are associated to these paths (IE_1, IE_2 and IE_3):

$$IE_1(C_1, C_5) = \min\{e_{12}, e_{24}, e_{45}\} = \min\{some, a\ lot, some\} = some; \quad (1)$$

$$IE_2(C_1, C_5) = \min\{e_{13}, e_{15}\} = \min\{much, a\ lot\} = much; \quad (2)$$

$$IE_3(C_1, C_5) = \min\{e_{13}, e_{34}, e_{45}\} = \min\{much, some, some\} = some. \quad (3)$$

Furthermore, apart from evaluating indirect effects IE, the total effect TE of element C_1 over element C_5 has to be taken into account. The total effect corresponds to the maximum evaluation associated to the three indirect effects, which in our case is:

$$TE(C_1, C_5) = \max\{IE_1(C_1, C_5), IE_2(C_1, C_5), IE_3(C_1, C_5)\} = much. \quad (4)$$

This result means that, on the whole, element C_1 imparts *much* causality to element C_5. Linguistic evaluations are translated to fuzzy numbers, i.e. triangular or trapezoidal fuzzy numbers, collected into input matrices and represented by a map graphically showing the entity of the relations among elements.

4 Real Case Study of an Italian Airport

4.1 Context Description

The civil airport sector has gone through deep structural modifications and developments over the last few decades. International airports no longer operate as mere providers of infrastructure services, but they can be considered as actual complex business organisations, offering a wide plurality of services with the consequent need of designing and implementing suitable cost management strategies. To such an aim, airport managers dedicate plenty of efforts to the diversification of income sources with the purpose of generating revenues from many diverse activities. This aspect also refers to the aggressive competition among international airports caused by such processes as liberalisation and privatisation, with consequent management of increasing passengers' flows as well as portfolio of routes and affiliated airlines.

Some preliminaries are herein reported to complement the context description according to definitions provided by regulatory sources, is necessary. An *aerodrome* is an area with well-defined boundaries, dedicated to the such activities as landing, take-off and ground movement operations from both civil and aviation military aircrafts, used for commercial, entertainment or training purposes. An *airport* is an aerodrome provided with additional infrastructures that are aimed at offering services for management of aircraft, passengers and goods. An airport is hence a highly complex environment, where the organic organisation of multiple and varied activities is required from several companies that have to simultaneously coexist and operate in the same physical area. The capability for promptly responding to precise standards and practices aimed at minimising risks is clearly crucial, something that has to be verified by proper airport certification processes.

We are herein analysing an Italian airport classified within the *small* category, which registered a yearly flow of around 500.000 passengers in the period antecedent to the outbreak of the COVID-19 pandemic. The company in charge of the airport management has been operating for several years by integrating as much as possible the administration of areas, infrastructures and plants, and by taking special care of maintenance activities. Furthermore, business processes are periodically reviewed in order to improve the quality of services, to optimise costs, operational times and profits. The organisation has the characteristics of a multi-business company, pushing towards continuous strategic consolidation by means of two main criteria. First, the clear attribution of responsibility to the various professional roles promotes a flexible structure, and second, staff activities have been centralised according to human resources management, maintenance and development, administration, finance and control, environment, safety and security, and so on. A total of seventy-eight employees are distributed to the related areas of competence. In this context, organisational aspects are clearly fundamental and proper actions of organisational risk assessment need to be implemented and continuously updated.

4.2 Results and Discussion

The HSE indicator tool previously presented in Sect. 2 has been analysed for the airport of reference with the support of a safety specialist. The responsible of the safety and security system in charge at the airport under consideration has been involved in view of his wide experience on organisational issues. As already illustrated, the present application implements an in-depth analysis of the HSE indicator tool making use of the combination between ANP and FCM, preliminary to the stage of employees' interviews. We specify that interviews will be led and recorded for producing the journal extension of the present work, where we also plan to carry out comparisons with other methodological approaches for organisational risk assessment. For example, methods proposed by Italian regulation authorities such as the national institute for occupational accident insurance (Italian acronym: INAIL) and/or the health and safety prevention service of Verona Province may be object of future evaluation.

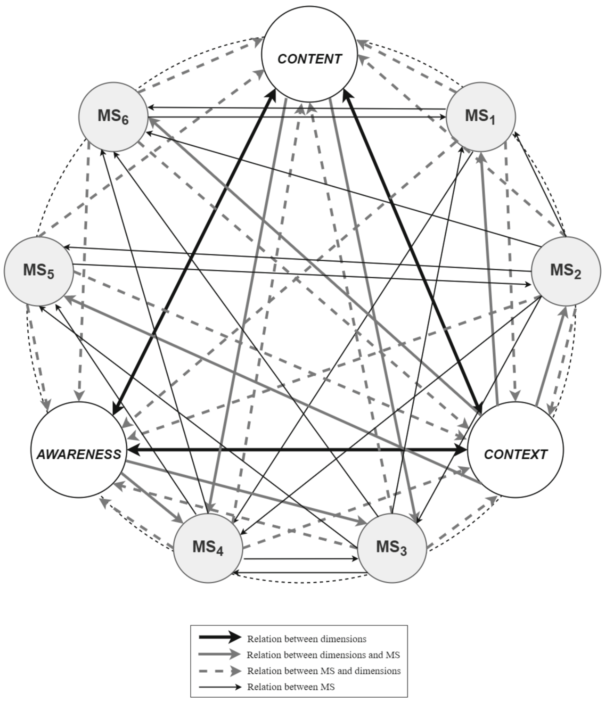

Fig. 2. Relationships linking dimensions and management standards

We now proceed by first applying the ANP technique to calculate the importance weights of the six MS. This will be done by first building the structure of interactions (shown in Fig. 2) formalising relations of dependence among MS with respect to the three main dimensions of reference discussed in Sect. 2.

The unweighted supermatrix (Table 2) has been built by means of the influence relations and preferences established by the involved expert, who was asked to pairwise compare the elements with identified relations of dependence.

Table 2. Unweighted supermatrix

	Goal	Cnt	Cxt	Aws	MS_1	MS_2	MS_3	MS_4	MS_5	MS_6
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cnt	0.500	0.000	0.700	0.250	0.000	0.000	0.400	0.400	0.000	0.000
Cxt	0.250	0.500	0.000	0.750	1.000	1.000	0.000	0.000	1.000	1.000
Aws	0.250	0.500	0.300	0.000	0.000	0.000	0.600	0.600	0.000	0.000
MS_1	0.199	0.232	0.185	0.174	0.000	0.000	0.000	0.200	0.000	0.200
MS_2	0.199	0.191	0.250	0.200	0.500	0.000	0.300	0.200	0.400	0.200
MS_3	0.199	0.114	0.225	0.159	0.200	0.000	0.000	0.600	0.300	0.300
MS_4	0.124	0.120	0.177	0.093	0.000	0.000	0.700	0.000	0.300	0.300
MS_5	0.148	0.239	0.088	0.185	0.000	1.000	0.000	0.000	0.000	0.000
MS_6	0.131	0.104	0.075	0.189	0.300	0.000	0.000	0.000	0.000	0.000

The weights obtained by AHP are reported in Table 2, whose columns have been normalised for calculating the weighted supermatrix Table 3.

Table 3. Weighted supermatrix

	Goal	Cnt	Cxt	Aws	MS_1	MS_2	MS_3	MS_4	MS_5	MS_6
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cnt	0.250	0.000	0.350	0.125	0.000	0.000	0.200	0.200	0.000	0.000
Cxt	0.125	0.250	0.000	0.375	0.500	0.500	0.000	0.000	0.500	0.500
Aws	0.125	0.250	0.150	0.000	0.000	0.000	0.300	0.300	0.000	0.000
MS_1	0.100	0.116	0.093	0.087	0.000	0.000	0.000	0.100	0.000	0.100
MS_2	0.100	0.096	0.125	0.100	0.250	0.000	0.150	0.100	0.200	0.100
MS_3	0.100	0.057	0.113	0.080	0.100	0.000	0.000	0.300	0.150	0.150
MS_4	0.062	0.060	0.089	0.047	0.000	0.000	0.350	0.000	0.150	0.150
MS_5	0.074	0.120	0.044	0.093	0.000	0.500	0.000	0.000	0.000	0.000
MS_6	0.066	0.052	0.038	0.095	0.150	0.000	0.000	0.000	0.000	0.000

The limit matrix has been then processed by raising the weighted supermatrix to successive powers until convergence. Table 4 reports the values of any of the columns of the limit matrix as well as the weights of MS in percentage. We can observe that the context dimension (cxt) is, on the whole, the most critical in terms of organisational risk management, having associated a weight of 47.56%.

Table 4. Dimensions and MS weights

Dim.	Limit matrix value	% weight	WS	Limit matrix value	% weight
Cnt	2.55E+15	27.27%	$\mathbf{MS}_1$	1.15E+15	12.28%
			$\mathbf{MS}_2$	2.19E+15	23.48%
Cxt	4.44E+15	47.56%	$\mathbf{MS}_3$	1.82E+15	19.52%
			$\mathbf{MS}_4$	1.67E+15	17.87%
Aws	2.35E+15	25.17%	$\mathbf{MS}_5$	1.81E+15	19.42%
			$\mathbf{MS}_6$	6.93E+15	7.43%

However, when we look at the single standards, higher weights correspond to MS_2 (control) and MS_3 (support), respectively referring to the content (cnt) and context (cxt) dimensions. These results indicate that, instead of focusing just on the most critical dimension and on the related MS of support and relationship, it would be preferable to dedicate special attention to the control MS (together with the support MS) for better managing stressful conditions of employees.

The last stage of the application consists in building the FCM for obtaining the total effects associated to relevant items of evaluation (items from Table 1). In such a way, specific aspects that can play a key role for promoting the efficient management of the work-related stress risk can be formally highlighted. Such a type of analysis offers opportunities for pursuing overall organisational optimisation. This is herein achieved by collecting fuzzy preference relations translating evaluations of mutual influence between pairs of elements, again expressed by the responsible of the safety and security system in charge as follows: VL (Very Low), L (Low), M (Medium), H (High), VH (Very High). We are herein reporting the FCM related to the MS of control and support, that are the standards with major significance resulting from the previous ANP application and in need of being managed with priority. The procedure has been initialised by collecting linguistic preferences from our expert, reported in Table 5.

These evaluations have been translated into trapezoidal fuzzy numbers and successively defuzzified by following the procedure implemented in [11]. The last column of Table 5 indicates the total effect of each item, obtained as the maximum between the two values of indirect effects.

The corresponding defuzzified matrix is not herein reported because of the limited space allowed. However, defuzzified values constitute the numerical values of input for building the FCM of Fig. 3, reproduced by iterating the Mental Modeler software. The map shows 106 connections, identified for 15 items, an average of 7.07 connections per item. Items CO_2 and CO_3 have associated evaluations of *medium* total effects for the control MS, while items SU_7 and SU_8 have associated evaluations of *high* total effects for the support MS.

Table 5. Connection matrix

ID	CO_1	CO_2	CO_3	CO_4	CO_5	CO_6	CO_7	SU_1	SU_2	SU_3	SU_4	SU_5	SU_6	SU_7	SU_8	IE	TE
CO_1	0	VH	H	VH	VL	VL	L	0	0	0	0	0	0	0	0	VL	L
CO_2	VH	0	VH	VH	L	L	M	0	0	0	0	0	0	0	0	L	M
CO_3	VH	VH	0	H	M	H	M	0	M	0	0	H	0	0	0	M	M
CO_4	VH	H	M	0	L	L	M	0	0	0	0	0	0	0	0	L	L
CO_5	L	M	M	L	0	VH	L	0	0	0	0	VL	0	0	0	VL	VL
CO_6	L	M	M	L	VH	0	L	0	VH	VH	0	0	0	0	0	L	L
CO_7	H	H	H	H	L	L	0	0	0	0	0	0	0	0	0	L	L
SU_1	0	0	0	0	0	0	0	0	M	H	VH	H	H	H	H	M	M
SU_2	0	0	L	0	0	VH	0	M	0	L	L	M	L	L	M	L	M
SU_3	0	0	0	0	0	VH	0	H	M	0	H	VH	M	H	VH	M	M
SU_4	0	0	0	0	0	0	0	VH	M	M	0	M	VH	VH	H	M	M
SU_5	0	0	H	0	0	VL	0	H	0	VH	H	0	H	M	VH	VL	VL
SU_6	0	0	0	0	0	0	0	VH	0	M	VH	H	0	VH	M	M	M
SU_7	0	0	0	0	0	0	0	H	VH	H	VH	H	H	0	H	H	H
SU_8	0	0	0	0	0	0	0	H	H	VH	H	VH	H	VH	0	H	H
IE	L	M	L	L	VL	VL	L	M	M	L	L	VL	L	L	M	–	–

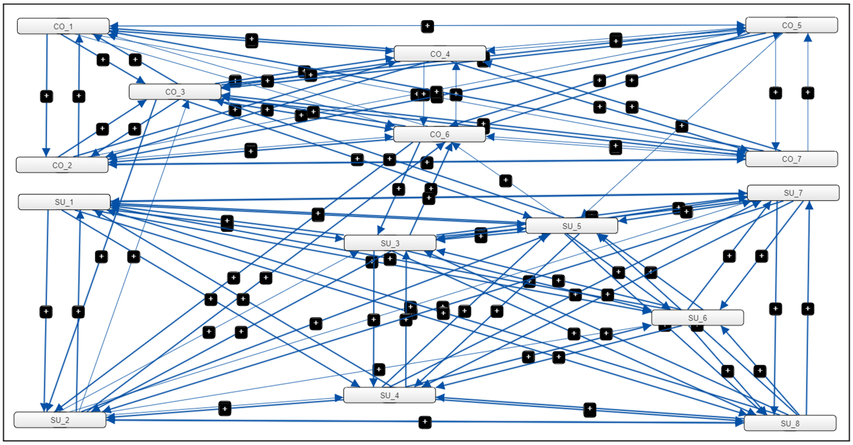

Fig. 3. FCM showing relationships among items of control and support MS

From a practical point of view, these results indicate that stressful conditions concerning standards of control would be realistically reduced if workers received less pressures concerning the rhythm and the organisation of their tasks. Furthermore, support standards would benefit if more attention was paid to such aspects as moral support and encouragement. FCM demonstrates as the discussed factors are mainly related with all the others, so that their priority management would imply general enhancement of working conditions. By implementing the procedure based on ANP and FCM is then clear that specific aspects can be identified and improved for managing work-related stress and for broadly reducing organisational risk at the airport herein presented.

5 Conclusions and Future Research

This research proposes a methodological integration between ANP and FCM as a novel application to the field of organisational risk management in complex business environments. First, ANP is helpful to establish priority organisational standards by analysing relations of dependence among MS. And second, FCM can highlight specific factors that influence global stressful conditions by effectively managing uncertainty. We designed an improved version of the HSE model for work-related stress risk evaluation. Our framework is capable of unveiling those items of the indicator tool that are in need of prominent attention on the basis of mutual relations of influence. Also, our model is less generic than the HSE tool, since it can be personalised according to the specific context of reference by involving inner expert preferences. Our approach was applied to an Italian airport company with meaningful outcome.

Future lines of work will aim to customise even more the tool of work-related analysis by referring to specific homogeneous groups of workers who share similar tasks, being then subjected to risks of similar nature. A decision support system elaborating answers provided by workers may be implemented to support in analysing personal perceptions of workers about significant stressful conditions.

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