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TEAM PERFORMANCE IN SAFETY CRITICAL SYSTEMS: REVIEW AND APPROXIMATION BY FUZZY-AHP

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ABSTRACT

The question of team performance still a big challenge for ergonomics in industrial and safety critical systems (SCS) where failure might generate a loss in life, significant economic damage or environmental harm. While the human factor is an important component of safety creation and while team work processes are primordial in SCS, it is important to monitor and enhance team performance to promote the global safety. In fact, there is no consensus on team performance (TP) modeling because of multitude of parameters and their inference involving different disciplines. In addition, an applicable numerical quantification and measurement of TP in ergonomics still needed. In this paper, we present a new TP model based on largely debated cognitive concepts, such as situation awareness and human reliability in systemic approach of safety management. The proposed model is a macro perspective of TP operation that could be generalized and applicable in different SCS. In the second part, we aim to benefit from the Fuzzy Analytic Hierarchy Process (FAHP) progress, as a tool of decision making, to propose a method of team selection. The TP model presented in first section is the basis of a FAHP numerical problem. This application is a novelty in approximating TP according to multi-criteria decision making modeling and proposes an applicable tool to practitioners and managers in industrial SCS. A numerical case study in railway is proposed to explicit the methodology of application.

Key words: *Team performance, situation awareness, Fuzzy- AHP, safety critical system.*

1. INTRODUCTION

This study is concerning safety critical systems where human performance affects directly and significantly the global safety, reference is made to critical domains as nuclear industries, aviation control, railway…. Indeed, it is largely discussed that human factor is responsible of approximately 70% of incidents that accurate in these contexts (70-80% in military and civil aviation [1].

The advance of technology, the increased complexity and the interdependencies between specialized jobs of a work process has leaded the SCS to adopt a team work organization. That is why team performance is critical for fulfilment of operational critical system tasks and a global success in the considered firms. The listed SCS environments are characterized by processes relying on effective team work and global performance of all specialized professions that intervenes to provide, “safely”, a product or a service.

Many works on ergonomics tried to explain and measure TP. Basically, all studies in TP are working separately in specialized domains (cognition, organization, physical human factors…). Our paper is concerned on a TP study based on a large background of advances in cognition, human factors and safety management combined to achieve a macro perspective of TP system.

In the first part of this paper, we present an overview of the concept of team performance in literature and highlight the parameters and variables listed as underlying the operational team performance. A new model of TP is then proposed to provide a global picture and understanding of TP mechanism. We refer to microwolds concept to underlie complexity, opacity and dynamicity of TP process. Next, we present a synthesis of different dimensions listed in literature that influence a dynamic critical team work process. The identified elements of TP are highlighted to understand the TP process, they are non-exhaustive and could be adapted to context of each safety critical organization.

In the second part, a similitude of the proposed model of TP to a fuzzy AHP problem is detailed. The purpose of this numerical application is to approach the measurement of TP throughout the proposed

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ergonomic model considered as unquantifiable and immerged by uncertainties. This constitute an initiation of a new reflection in cognitive research based on objective numerical measurement and prediction.

Our research on modeling team performance and exploring FAHP applied to ergonomics to apprehend the performance in complex safety systems is basically motivated by a deep need in:

- A global model of team performance that takes into consideration several aspects treated in ergonomics
- Numerical study that deals with subjectivity and uncertainty in team performance assessment
- Applicable numerical methodology to approximate and rank teams' performances in critical systems.

The selection of FAHP method is based on the fact that AHP has been much used in most domains where selection of "better/suitable" alternative depends on a set of criterions and sub-criteria that can be ordered in hierarchical manner. Moreover, the fuzzy logic deals with uncertain character of variables, and it is argued in literature that the integration of the fuzzy aspect to AHP methodology offers better opportunities.

Our reflection is motivated by a large background of complex problems that have been approached and solved by the FAHP methodology such as supplier selection, job's candidate selection, risk assessment, project choice and safety in construction. Nevertheless, we believe that this is the first paper that deals with team selection according to FAHP based on ergonomic modeling in critical system.

A numerical case study is then detailed to explicit the applicability of the FAHP to team performance assessment in organization where it still a challenge to assign team members depending on ergonomic variables.

2. TEAM PERFORMANCE MODEL

2.1. Theoretical framework for modeling Team performance

2.1.1. Cognitive teamwork

Team cognition received much attention in high reliability domains in order to promote effective teamwork and reduce risks. Military and aviation domains (followed more recently by healthcare) are leaders in cognitive team studies that tries to understand, model and monitor the human factor performance and enhance the safety output of these organizations.

There is a panoply of definitions and theoretical models of teamwork that has been presented in the last decades. The most of these frameworks highlighted the dynamicity, tasks interdependencies, and coordination of team work process to achieve final shared goal [2] [3] [4].

Salas [5] defined a team as "a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership". Our interest in this definition raises toward an important listed concept that matters for ergonomics which is "adaptation". It is about the ability of the team members to vary dynamically, according to other team members' strategies and overall status of the dynamic system [6].

In teamwork studies, two different dimensions appeared; the teamwork process and the task work process [7] [8]. The first one is about a holistic approach of a team working together to achieve final goal, and the second one is about focusing on team members' tasks as a core of technical competencies involved in the team process.

Theoretical studies on teamwork effectiveness showed that shared goals and knowledge (i.e. shared mental models and shared strategies), and effective communication and coordination are the majorly listed concepts that foster collaborative work. The team performance is presented as a process (and not a resultant or product) related to success and satisfaction of task work and teamwork processes [9]. Team performance is then cross disciplinary, dynamic and multi-level concept that that relates on individual and team cognition [10].

2.1.2. Team situation awareness

The concept of SA was born from a need to explain the cognitive process of human interaction with operational system and tried to model and understand non observable processes that affect decision making and then human performance in critical systems (mainly in aviation domain). SA was majorly explained through observable behaviors and measures of the actions and decisions of the operators and its compatibility to defined objectives. Different methodologies of SA measurement emerged to assess elements of defined SA depending on domains and operational context.

Endsley's researches in SA proposed the much known individual SA model based on the three levels: perception of elements, comprehension of situation and projection of future status [11]. The author defined the SA as a dynamic process of decision making through the focus on critical elements of system and its environment as a first step (1st level). The received information is mapped according to the mental models of the operator (2nd level) and then proposing possible future status / actions (3rd level) from which the decision making is chosen and implemented as an executed action.

Team SA is undeniably more complex, difficult and poorly understood [12] [7]. This is proved by the absence of unified vision and definition of collaborative SA and it is mainly due to:

- Different teamwork designs and perceptions that has leaded to various constructs in SA: Individual SA of team members (task work SA), shared SA, distributed SA (involving the joint cognitive systems and used artefact [13], the generic SA off the whole team, 'transactive' SA based on transactive memory [14] where agents (human and artefacts) are supposed to enhance the awareness of each other through SA 'transactions', …
- A census of a number of system's factors and team processes that may interact and affect individual and team SA. Authors focus on elements influencing the process of acquisition of SA and involved team processes such as communication [5], coordination rather than SA itself.

Many team SA modeling are proposed in literature (team SA model of Salas [5]), distributed cognition approach [15], nevertheless, the Endsley's model of individual SA [11], constitute a basis for an extended team SA [3] [16] that received much approval for approaching real team SA.

2.1.3. Human reliability in the systemic approach

The basis of the systemic model of error management is that human is fallible and that errors are to be expected. The systemic approach is about the focus on causes so that the error management can build necessary defenses, barriers and safeguards to avert errors, avoid incidents or mitigate their effects. The Swiss cheese model proposed by Reason [17] [18] admits that different layers of system's protection are to be assimilated to swiss cheese with active holes, that change randomly, representing the weaknesses of each barrier. The alignment of the wholes among the system's layers is the cause of the hazardous incident.

The systemic approach of accident analysis supports the reinforcement of safety defenses and barriers of a system. That is to say that the safety resilience of a system relies on a set of means and functions that can ensure the safety of people and assets and protect from unwanted events [19] [20]. Safety functions were defined and classified by Harms-Ringdahl as "a technical, organizational function, a human action or a combination of these functions that reduces the probability and/or consequences of accidents and other unwanted events in a system" [21]. This definition highlights the importance of organizational performance and individual accomplishment as safety functions.

In critical safety domains such as nuclear industry, aviation or military, accidents related to human error were majorly explained by a luck of SA, poor SA or loss of SA as a causal factor [22]. The cognitive processes of SA tried to explain human mechanisms of decision making and reinforce the human resilience to error in individual and team contexts. That is a basis of our reflection about real implication of SA in the systemic approach to adapt and anticipate individual and team real time decision making to promote performance in high reliability contexts such as SCS.

Collaboration and combination between the advances of identified domains still needed. In addition, Cognitive works and SA studies for TP measurement focus on experimental methods (simulation, freeze probe technique, real time probe…) while the systemic safety approach relies on accident and incident analysis. We propose in next paragraph a holistic model that gathers and makes links between all elements of TP in the mentioned state of art from literature. Furthermore, the measurement of TP in following sections is based on criteria and parameters identified in listed domains, according to historical performances for each criteria and their relative importance depending on the context of study.

2.2. Team performance model

In this section, and based on what precedes, we present our modeling of team performance (Figure 1). The proposed model is a dynamic central system that describes the complex relations between the SA of individual and the SA of the group and then between their respective performances. The continuous process of regulation for individual and

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team is highlighted by a closed loop that takes into consideration the feedback of previous performances.

The nucleus of the proposed model is based on the three aspects that we found in microworlds and applicable to human cognition [23] [24] [25]. It is about opacity, complexity and dynamicity. The individual SA is an inseparable part of the team SA and, as argued in team SA literature review, we believe that it still a challenge to propose a general applicable model that defines the interaction of individual team members SA in complex systems. The proposed model of team performance underlies the effect of individual SA on team SA and TP according to opaque and complex interactions between team members.

The dynamic process of regulation and assertiveness of the operator's SA and performance toward the output of system is dependent of a series of decision making and is a real time process as described in microwolds studies.

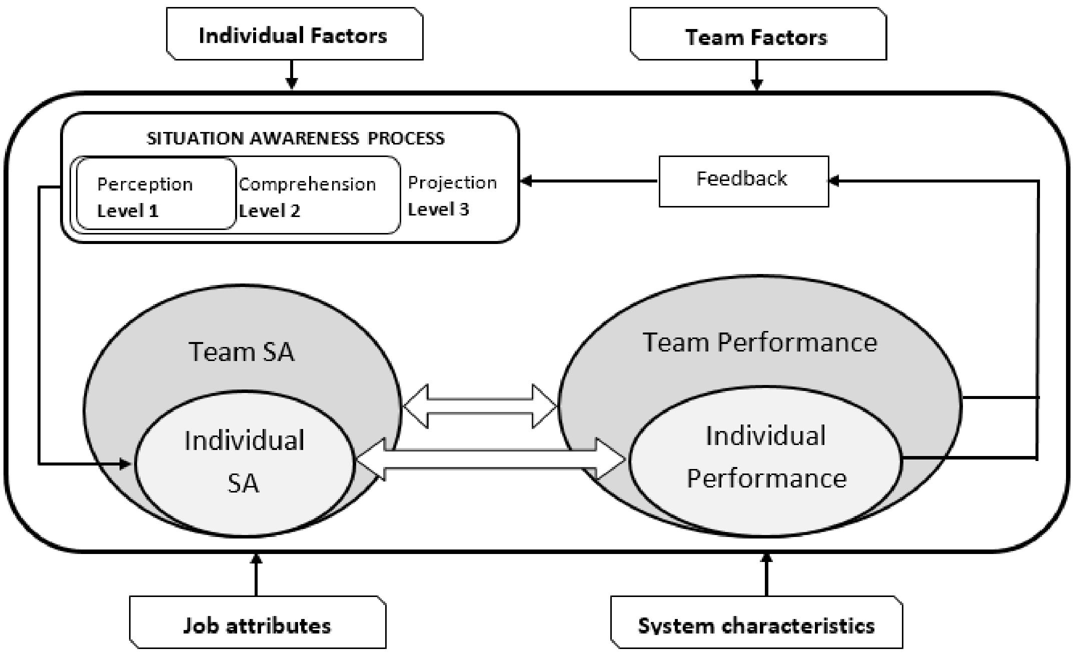

Figure 1 : Team performance model (based on Endsley's SA process)

The TP model relies on pillars that represent a global synthesis and combination, in one side, of elements of system and its environment that influence SA and, in the other side, of components identified as barriers and safeguards in the systemic approach of SCS. Next paragraphs detail the identified groups for our study that represents main inputs for the global performance of TP model.

2.2.1. Individual factors

Individual factors are the variables having direct or implicit effect on the three levels of situation awareness. Four elements are distinguished from the state of the art which are: personal factors, skills and abilities, motivations and vigilance.

Personal factors are about physical parameters that varies among individuals in term of physical capabilities and anthropometrical features such as age, height and weight but also multi-dimensional features as human forces. Sensory and motor disabilities could be extreme examples of physical factors that alter human performance in SCS. Other types of variables can be identified such as physical and mental fitness, Long term memory (LTM) and mental models.

Skills and training represents the technical and non-technical skills. Technical ones are related to knowledge acquired and developed by the operator during the professional experience. Non-technical capabilities are about managerial competencies such as stress and fatigue management, supervision and leadership.

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Many cognitive works in ***motivation*** emerged to advance theories and explain the undeniable role of motivation to enhance individual and team performances. Latham and Pinder proposed the much known theories of goal-setting, social and organizational justice [26]. Meyer et al. [27] highlighted employee commitment and motivation as powerful factor of improving individual determination and focus theory. Concretely motivations are promoted by the need of professional fulfillment and growth detailed on Maslow's pyramidal needs [28], i.e. the need of moving up on functional hierarchy scale or the motivation to get gratified by the rewarding system.

Vigilance is one of factors influencing SA and its decrement may affect directly human performance. The variation of the degree of vigilance is mainly related to the rhythmic fluctuation of vigilance (circadian and ultradian vigilance), sleeping troubles, alcohol ingestion or the use of some medicines as psychotropic [29]. For example, Dawson and Reid experimented that after 24 hours without sleep is equivalent to blood alcohol of 10% and lead to 30% decrease in performance [30].

2.2.2. Team factors

We identify in this section the mainly three groups of team factors: communication, pattern of distribution, team experience and global synergy.

There is no doubt that the most evoked dimension when it is about the team work process is ***communication***. Communication can represent the tacit and explicit tools of information exchange, formal and informal, that fosters the construction of a sharing understanding and shared SA. Roth et al. argued that proactive communication enhances the global efficiency, safety and resilience to error. Failures in communication can lead to errors, impact team performance, and may cause disastrous accidents in SCS [31].

We assume that the ***Pattern of distribution*** represents an important aspect of teamwork performance. While communication and team SA are contextualized and adapted dependently on the form of the distribution (i.e. distribution is central in distributed SA), we found that the pattern of distribution is one of the team factors to consider. Kitchin and Baber distinguish three different Patterns of Distribution: "Spatial distribution" that focuses on having team members together or distantly and affects information sources and interfaces, "structural distribution" that is based on links between agents and artefacts which conditions communication methods, and "Functional distribution" concerned with responsibilities and roles in the team process [32].

Team experience is about the experience of the team members together as a team work. Experienced teams develop a common understanding, denoted in team cognition by *shared mental models*, to apprehend and anticipate each other's needs and adapt their actions according to defined task work [33]. The analysis in commercial aviation of agency's database by the National Transportation Safety Board showed that 73% of accidents occur in the first crew flight together [34].

The ***Synergy*** of a team is one of key factors of team work success. Our reflection about synergy leaded us to highlight the mechanism, i.e. informal cooperative strategies [31], for obtaining performances of a group members greater than their performance when they are working separately. In other words, a good synergy in team work enhance individual performances and the global one, compared to the simple sum of their independent fulfillment. The largely given example is about the football players team where it is deduced that it is not about collecting best players to have the best football team.

2.2.3. Job characteristics

In SCS the first concern and focus is about safety. Organizations in these contexts have to improve their productivity without compromising safety or affecting operator's capabilities. We propose to detail the factors related to job characteristics in three identified groups: criticality, activity impact and safety impact.

Criticality is about the importance of the considered team work process for the activity of the organization. The importance can be measured in term of economic impact, strategic issues or the image of the company that might be jeopardized.

The ***activity impact*** of the work process concerns the effect of executing demanded tasks on operators' capabilities. Occupational health management emerged in the last decades to develop sustainable performance by taking into consideration individuals capabilities and limits [35]. For our study, we think that individual and team performances are correlated to the activity impact that has to be esteemed in short, medium and long term.

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Meanwhile ***Safety impact*** in SCS is primordial, the performance of a teamwork process has to be adapted to evaluated risks. That is to say that safety impact and team performance are closely dependent and have to be fairly dimensioned. Safety impact assessment can be elaborated toward identified safety issues by implementing risk based methodologies and safety impact factors studies.

2.2.4. System characteristics

On one hand, situation awareness modeling highlighted environmental factors and system design that affect the SA acquisition such as ***complexity***, ***automation*** and ***interfaces design***. Indeed, while the first level in the SA process is the perception of information and elements from the system, the surrounding environment, and from other team members, the listed characteristics had an important impact on individual and team performance [3] [11].

On the other hand, the systemic approach concerned with the safety barriers focuses on system's barriers as one of safeguards from accidents [36]. The system and interfaces design, teamwork processes definition, automation monitoring, are examples of elements of the considered system that foster the team performance and the global safety.

3. FUZZY AHP

3.1. Application of FAHP to team performance

The purpose of this study is to help decision makers and managers to form and assign the "suitable" team to accomplish a critical teamwork process according to criteria identified in the team performance model.

From among the accepted assumptions for this paper and the numerical case study are:

- The focus is only on the identified criteria of the TP model that will be taken into consideration for evaluation and ranking. This can be adapted to context in further applications.
- Social criteria, interdependencies and inference of considered criteria, are not considered for this study.

AHP offers a tool of assessment by pair-wise comparison between criteria, sub criteria and alternatives that represents alternatives of team assignment in this paper research.

The comparison is based on evaluation of criteria and sub criteria by a single or a group of experts and decision makers. An advantage in AHP is the concept of consistency measure that is much discussed in literature [36] and highlights the importance in decision making problem to estimate the consistency of the collected judgements.

However, AHP has been criticized for "forcing" a numerical assessment of experts and for being unrealistic by not taking into consideration uncertainty, incompleteness and subjectivity in provided judgements (example is given in case of verbal judgement) [38] [39]. The listed constraints are present and importantly considered in ergonomics and they had been approached by the fuzzy logic. AHP has also been adapted to solve problems in case of fuzzy variables denoted Fuzzy AHP.

While team work involves a multi-dimensional model with relevant criteria and sub criteria of each dimension, it is suitable to explore the team research as an AHP problem. Moreover, the nature of involved variables may be subjective and non-precise, that is why it is adequate to take into consideration the fuzzy character of the AHP methodology and adopt the FAHP.

3.2. FAHP Theoretical framework

Conventional AHP was first developed by Saaty [40], his works concerned the decomposition of complex problem into hierarchical structure of simple elements. The AHP methodology helps to make a decision and choose among a multitude of alternative according to several criteria and sub-criteria throughout a pair wise comparison. The implementation of conventional AHP consists on the following steps:

- The structure of the problem hierarchically and its decomposition it into main elements: the top level represents the goal of the decision making problem, the next levels are the criteria and sub criteria that affect the decision. Alternatives are in the bottom of the hierarchy to express the possibilities of the decision making problem.
- calculation of the local priorities that denotes weights of criteria, sub-criteria and alternatives of the hierarchical problem based on the expert's comparison and judgment.
- Calculation of global priorities for ranking the alternatives and selection of the suitable possibility. This step is based on a weighted sum of local priorities.

The Fuzzy AHP is based on the application of conventional AHP to fuzzy environment and was initiated by Buckley [41] [42] when he used fuzzy numbers to solve AHP structures.

3.2.1. Fuzzy numbers

Fuzzy logic has been introduced by Zadeh [43] to deal with uncertainty, subjectivity and vagueness in expression of imprecise affirmation. Zadeh suggested fuzzy numbers to express the degree of membership to a set that can be represented by a membership function. The triangular and trapezoidal are the most used membership function forms because of their simplification of mathematical calculation without significant loss of precision. For this paper we make the choice of referring to the triangular function as represented in Figure 2 by $\mu_{\tilde{A}}(x)$:

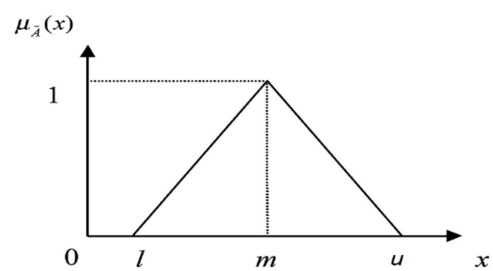

Figure 2: Triangular fuzzy number

Where: $(l; m; u)$ is triple with $l \leq m \leq u$
And:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0 & otherwise \end{cases} \quad (1)$$

Let us consider $X_1 = (l_1; m_1; u_1)$ and $X_2 = (l_2; m_2; u_2)$ two triangular fuzzy numbers (TFNs). The most used logical fuzzy operators are defined by:

$$X_1 \oplus X_2 = (l_1 + l_2; m_1 + m_2; u_1 + u_2) \quad (2)$$

$$X_1 \otimes X_2 = (l_1 \times l_2; m_1 \times m_2; u_1 \times u_2) \quad (3)$$

$$X_1{}^{-1} = (l_1; m_1; u_1)^{-1} \approx (\frac{1}{u_1}; \frac{1}{m_1}; \frac{1}{l_1}) \quad (4)$$

Fuzzy logic offers the possibility of approximating domains where a judgement may be vague or numerically unquantifiable. The linguistic variables had been studied and approached by fuzzy logic according to membership functions [44]. For our study, we make the choice of defined linguistic comparison scale and the corresponding triangular fuzzy numbers as detailed in Table 1.

Table 1:Triangular fuzzy corresponding scale

Linguistic terms comparison	*Scale of fuzzy numbers*
Equally Important (eq. Imp)	(1,1,1)
Weakly Important (W. Imp.)	(1;2;3)
Fairly Important (F. Imp)	(2;3;4)
Strongly Important (S. Imp.)	(3;4;5)
Absolutely Important (A. Imp.)	(4;5;6)

3.2.2. Fuzzy pair wise comparison matrix

Experts and decision makers select their judgement and preference notation of criteria. A pair wise comparison matrix is composed for each expert that we refer to by $\tilde{A}^k$ (that represents the pair wise comparison matrix for the K^{th} expert) where :

$$\tilde{A}^k = \begin{bmatrix} \tilde{C}_{11}^k & \cdots & \tilde{C}_{1n}^k \\ \vdots & \ddots & \vdots \\ \tilde{C}_{n1}^k & \cdots & \tilde{C}_{nn}^k \end{bmatrix} \quad (5)$$

$\tilde{C}_{ij}^k$ are triangular fuzzy numbers (TFNs) and represents the K^{th} expert's preference of i^{th} criteria compared to j^{th} criteria, with: $\tilde{C}_{ij}^k = (l_{ij}^k; m_{ij}^k; u_{ij}^k)$, n the number of compared criteria and:

$$\tilde{C}_{ij}^k = \frac{1}{\tilde{C}_{ji}^k} \approx (\frac{1}{u_{ij}^k}; \frac{1}{m_{ij}^k}; \frac{1}{l_{ij}^k}) \text{ and}$$
$$\tilde{C}_{ij}^k = (1; 1; 1) \text{ for } i = j$$

In case of many experts, the pair wise comparisons are averaged according to the fuzzy geometric mean method of Buckley [42] following the formula:

$$\tilde{C}_{ij} = (\prod_{i=1}^{d} \tilde{C}_{ij}^k)^{\frac{1}{d}} \quad (6)$$

where d is the number of experts and where $\tilde{C}_{ij}$ still a TFN with: $\tilde{C}_{ij} = (l_{ij}; m_{ij}; u_{ij})$

Then the pair-wise comparison matrix (4) become:

$$\tilde{A} = \begin{bmatrix} \tilde{C}_{11} & \cdots & \tilde{C}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{C}_{n1} & \cdots & \tilde{C}_{nn} \end{bmatrix} \quad (7)$$

3.2.3. Value of extent analysis

Many methods are proposed to handle the fuzzy AHP [42] [45] [46]. The extent analysis introduced by Chang is much used for calculation of local priorities and ranking the alternatives [46] [47]. His application concerned triangular fuzzy numbers, supported by real case study, and was encouraged because it facilitates the computational model. In this paper we refer to Chang methodology of extent analysis. The first step is then to calculate the synthetic extent values S_i based on the comparison matrix $\tilde{A}$ with respect to the criterion i according to the formula:

$$S_i = \sum_{j=1}^{m} \tilde{C}_{ij} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{C}_{ij} \right]^{-1} \quad (8)$$

So that:

$$\sum_{j=1}^{m} \tilde{C}_{ij} = (\sum_{j=1}^{m} l_{ij} ; \sum_{j=1}^{m} m_{ij} ; \sum_{j=1}^{m} u_{ij})$$

And: $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{C}_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} u_{ij}} ; \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} m_{ij}} ; \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}}\right)$

3.2.4. Approximating fuzzy priorities:

The second step is the determination of the degree of possibility. It is the about the possibility that fuzzy preference of criterion i is higher than the preference of criterion j denoted $V(S_i \geq S_j)$ and defined according to Chang by:

$$V(S_i \geq S_j) = \begin{cases} 1 & if \quad m_i \geq m_j \\ 0 & if \quad l_i \leq u_j \\ \frac{l_i - u_i}{(m_j - u_j) - (m_i - l_i)} & otherwise \end{cases} \quad (9)$$

Where: $S_i = (l_i; m_{i;} u_i)$
and $S_j = (l_j; m_{j;} u_j)$

The third step is the determination of the degree of possibility for a triangular (more generally convex) fuzzy number S_j to be greater than k triangular fuzzy numbers S_j $(j = 1,2, \dots k)$, $j \neq i$. This was proposed by Dubois and Prade [48] to be defined as:

$$V(S_i \geq S_1, S_2, \dots, S_k) = \min(V(S_i \geq S_j)) = w'(S_i) \quad (10)$$

$w'(S_i)$ represents the relative weight of the criterion i over other criterion and it is a non-fuzzy number. $w'(S_i)$ are calculated for $i = 1,2, \dots n$ (n the number of criterion) and normalized to $w(S_i)$, by analogy to the conventional AHP methodology, to obtain the weight vector:

$$W = (w(S_1); w(S_2), \dots, w(S_n))^T \quad (11)$$

3.2.5. Consistency test:

The consistency test consists on an evaluation of the quality level of comparison matrix and the provided judgements [49]. The evaluations of experts are considered consistent if CR, the consistency ratio is less than 10% where:

$$CR = \frac{CI}{RI} \quad (12)$$

With CI and RI are respectively the consistency index and the random consistency index. The consistency index is calculated according to the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (13)$$

Where λ_{max} is the eigenvalue obtained by averaging the eigenvalues of all pair wise comparison matrix.

The random consistency index depends on number of criteria as proposed in Table 2:

Table 2 :Values of RI depending on number of criteria

n	3	4	5	6	7	8	9	10
RI	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

4. CASE STUDY:

The detailed case study highlights, in one hand, the advantage and the profitability of FAHP in team assignment for an organization where team performance management is an important vector of safety creation. In the context of railway company, where safety is crucial, the importance of team selection according to a set of inferring criteria still critical for safety managers and experts. In the other hand, the application of the team performance model proposed in first section will help to deal with complexity of team selection problem in safety operating of the railway company. The decision making problem is about assigning of a teamwork to a specific work process in a way to achieve safety objectives (i.e. predefined risk matrix, frequency of accuracy and severity of incidents) and improving productivity. In the following paragraphs we will

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detail some of the most important elements evoked in TP model that are crucial in our case study.

In term of individual performance in railway, there is no doubt that an operator cannot exert without passing a serial of medical examinations that shows his physical capabilities to perform in this safety critical context. The medical reviews are programed and realized in determined frequencies that depends mainly on the age of operators. These procedures represent the main side that highlights the importance of personal factors for team members in railway.

Another obligatory and critical element for operators in railway are the clearances for exerting in safety domains. The habilitations to handle artefacts in safety installations or to attain train driving cab and exert in driving professions are conditioned by the fulfillment and success in the training sections and simulations. The maintain of theses clearances is controlled and regulated by systemic tests which are inspected and audited to ensure the respect of their fulfillment. The experienced operators in railway are considered as a source of knowledge to be transferred to new arrivals. The controversy is than to equilibrate between physical capabilities, more maintained for young operators, and the degree of mastery and knowledge of the technical systems, more developed for older and experimented operators and ensuring the knowledge transfer among operators. The mentioned habilitations and training refer to skills and abilities as individual factors in TP model.

Job attributes concern at a first level the safety impact of the considered team work process. On the second level it is about the criticality of the operations in term of importance for productivity: bottleneck work centers, criticality for respect of punctuality, realization of transportation plan and fulfilment of operational objectives. We think that the activity impact on operator, his physical capabilities and vigilance in duration are to be considered as another important element of the job attributes.

Furthermore, and as argued in TP model, the team's factors are important components of the global performance in the work process. Intergenerational conflict, team knowledge and information sharing and communication are relevant to team management in the studied context.

The numerical case study is about a selection of a team, by FAHP problem solving, among three proposed teams according to TP model components. The first team (denoted in the following Team 1) is composed of novice operators and is characterized mainly by good synergy, effective communication, great motivations and important physical capabilities that are profitable for the considered work. The second team (Team 2) is combined of experimented and novice operators; its major attributes are intergenerational conflicts, luck of sharing information and difficulties in communication. The third team (Team 3) is an experimented team of former collaborators that have important technical knowledge in the railway operating profession, remarkable complicity and synergy, but also relatively demotivated agents.

4.1. Hierarchical structure

Team performance is a resultant of inference of elements identified in literature. The hierarchical structure of the detailed problem is prepared according to elements of TP model.

An assumption is that we assume that for our case study the characteristics of the system are fixed for the three selected teams so that three main criteria are considered as represented in Figure 3.

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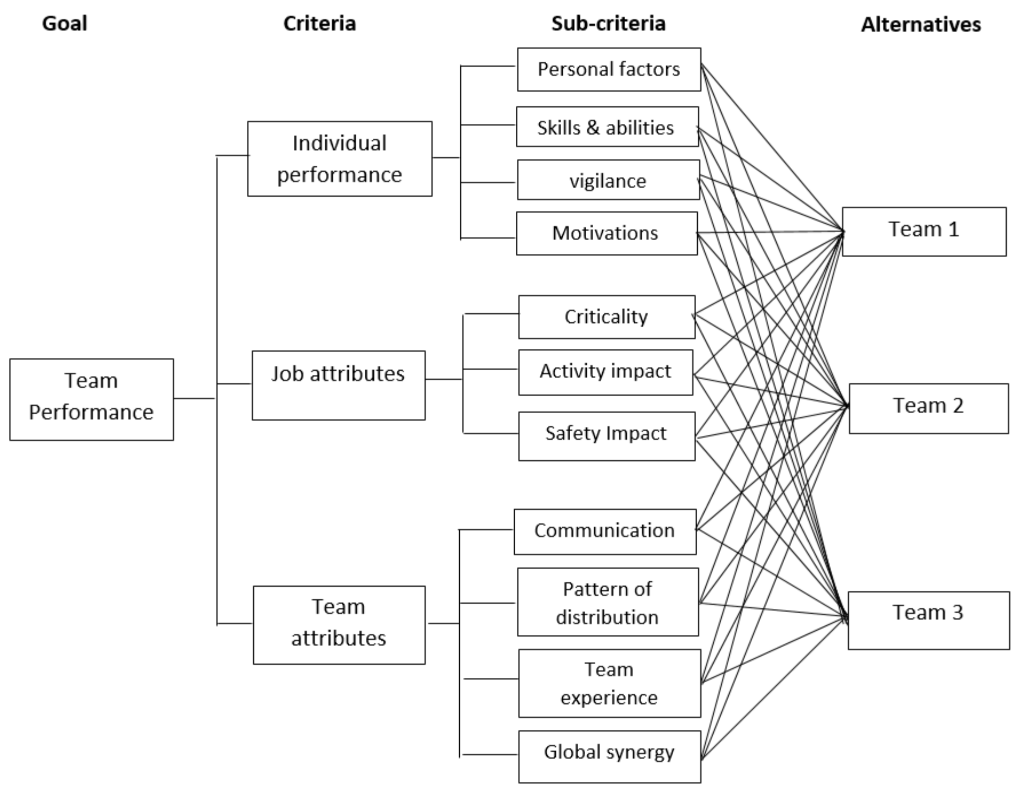

Figure 3: Hierarchical structure of TP problem

4.2. Experts Judgement

The adopted methodology consists on the administration of questionnaires to a group of managers and experts in railway composed of thirteen experts. The questionnaire is structured into tables based on examples presented in Table 3 and Table 4 and on comparison scale introduced in Table 1. The collected responses are the basis of expert's judgement for the importance of criteria and sub-criteria detailed in the hierarchical structure.

The same methodology is followed to assess the expert's judgements for each team (representing alternatives) according to each sub-criterion. Table (5) represents an example of framework to team's evaluation according to a definite sub-criterion.

Table 3: Comparison table of main criteria

	Left criteria is greater important					Right criteria is greater important				
	A. Imp.	S. Imp.	F. Imp.	W. Imp.	Eq. Imp.	W. Imp.	F. Imp.	S. Imp.	A. Imp.	
Individual performance										Job attributes
Individual performance										Team attributes
Job attributes										Team attributes

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Table 4: Comparison table of sub-criteria relatives to Individual performance

	Left criteria is greater important					Right criteria is greater important				
	A. Imp.	S. Imp.	F. Imp.	W. Imp.	Eq. Imp.	W. Imp.	F. Imp.	S. Imp.	A. Imp.	
Personal factors										skills/abilities
Personal factors										vigilance
Personal factors										Motivations
skills/abilities										vigilance
skills/abilities										Motivations
vigilance										Motivations

Table 5: Example of comparison table of alternatives according to a sub-criterion

	Left Team is greater satisfying sub-criteria					Right Team is greater satisfying sub-criteria				
	A. Imp.	S. Imp.	F. Imp.	W. Imp.	Eq. Imp.	W. Imp.	F. Imp.	S. Imp.	A. Imp.	
Team 1										Team 2
Team 1										Team 3
Team 2										Team 3

4.3. Computation of local priorities

We think that developing special software tool is not necessary because of the availability of many solutions (Expert choice, excel templates…). For our case study, an Excel template is developed to calculate intermediate results and final outputs.

Correspondence between proposed linguistic variables and fuzzy numbers are made according to Table1. Pair-wise comparison matrixes are built by averaging the experts' notation according to formula (6) as well as for main criteria and sub-criteria according to Tables (6 to 9). Consistency of each comparison matrix are calculated according to equations (12) and (13).

Table 6: Pair-wise comparison of main criteria

	Individual performance	*Job attributes*	*Team attributes*
Individual performance	(1 ;1 ;1)	(0,448 ;0,617 ;0,932)	(0,925 ;1,318 ;1,781)
Job attributes	(1,073 ;1,621 ;2,235)	(1 ;1 ;1)	(0,814 ;1,194 ;1,668)
Team attributes	(0,561 ;0,758 ;1,082)	(0,599 ;0,838 ;1,229)	(1 ;1 ;1)

Consistency of comparison matrix CR=0,03<0,1

Table 7: Pair-wise comparison for sub-criteria of Individual performance

	Personal factors	*skills/abilities*	*vigilance*	*Motivations*
Personal factors	(1 ;1 ;1)	(0,534 ;0,736 ;1,064)	(0,342 ;0,451 ;0,647)	(0,969 ;1,390 ;1,904)
skills/ abilities	(0,940 ;1,359 ;1,872)	(1 ;1 ;1)	(0,435 ;0,589 ;0,861)	(0,833 ;1,230 ;1,715)
vigilance	(1,546 ;2,216 ;2,926)	(1,161 ;1,698 ;2,297)	(1 ;1 ;1)	(1,218 ;1,774 ;2,345)
Motivations	(0,525 ;0,720 ;1,032)	(0,583 ;0,813 ;1,201)	(0,426 ;0,564 ;0,821)	(1 ;1 ;1)

Consistency of comparison matrix CR=0,01<0,1

Table 8: Pair-wise comparison for sub-criteria of Job attributes

	Criticality	*Activity impact*	*Safety Impact*
Criticality	(1 ;1 ;1)	(1,104 ;1,621 ;2,252)	(0,525 ;0,682 ;0,948)
Activity impact	(0,444 ;0,617 ;0,906)	(1 ;1 ;1)	(0,448 ;0,608 ;0,879)
Safety Impact	(1,055 ;1,466 ;1,818)	(1,137 ;1,645 ;2,234)	(1 ;1 ;1)

Consistency of comparison matrix CR=0,01<0,1

Table 9: Pair-wise comparison for sub-criteria of Team attributes

	Communication	*Pattern of distribution*	*Team experience*	*Global synergy*
Communication	(1 ;1 ;1)	(1,173 ;1,774 ;2,378)	(0,812 ;1,148 ;1,573)	(0,826 ;1,173 ;1,622)
Pattern of distribution	(0,421 ;0,564 ;0,852)	(1 ;1 ;1)	(0,410 ;0,551 ;0,801)	(0,483 ;0,647 ;0,948)
Team experience	(0,636 ;0,871 ;1,232)	(1,249 ;1,814 ;2,439)	(1 ;1 ;1)	(0,627 ;0,871 ;1,249)
Global synergy	(0,616 ;0,852 ;1,211)	(1,055 ;1,546 ;2,072)	(0,801 ;1,148 ;1,595)	(1 ;1 ;1)

Consistency of comparison matrix CR=0<0,1

4.3.1. Calculation of local priorities for main and sub criteria:

Let us calculate the fuzzy synthetic extent of main criteria. The fuzzy synthetic extent S_i with respect to the criteria j is calculated according to equation (8) based on fuzzy sum of rows of Table 6.

$$S_{\text{Individual performance}} = S_1 = (2{,}372\,;2{,}935\,;3{,}714) \otimes (7{,}419\,;9{,}346\,;11{,}928)^{-1} = (0{,}199\,;0{,}314\,;0{,}501)$$

$$S_{\text{Job attributes}} = S_2 = (2{,}886\,;3{,}815\,;4{,}904) \otimes (7{,}419\,;9{,}346\,;11{,}928)^{-1} = (0{,}242\,;0{,}408\,;0{,}661)$$

$$S_{\text{Team attributes}} = S_3 = (2{,}161\,;2{,}596\,;3{,}311) \otimes (7{,}419\,;9{,}346\,;11{,}928)^{-1} = (0{,}181\,;0{,}278\,;0{,}446)$$

Calculation of degree of possibility V computed for the criteria “Individual performance”:

$$V(S_1 \geq S_2) = \frac{0{,}242 - 0{,}501}{(0{,}314 - 0{,}501) - (0{,}408 - 0{,}242)} = 0{,}733$$

$$V(S_1 \geq S_3) = 1$$

The relative weight of the criteria “Individual performance” is then:

$$w'(S_1) = \min(0{,}733; 1) = 0{,}733$$

The same way all degree of possibility $V(S_i \geq S_j)$ for $i = 1{,}2{,}3$ are calculated and normalized for other main criteria. Tables 10 to 13 synthetize the calculation of local priorities for main and sub-criteria of our case study (based on Tables 6 to 9).

Table 10: Evaluation of local priorities for main criteria

	Fuzzy sum of rows	*Fuzzy synthetic extent*	*Relative weight $w'(S_i)$*	*Normalized weight $w(S_i)$*
Individual performance	(2,372;2,935;3,714)	(0,199;0,314;0,501)	0,733	**0,313**
Job attributes	(2,886;3,815;4,904)	(0,242;0,408;0,661)	1,000	**0,427**
Team attributes	(2,161;2,596;3,311)	(0,181;0,278;0,446)	0,610	**0,260**
	Sum of rows (7,419;9,346;11,928)			

Table 11: Evaluation of local priorities for sub-criteria of Individual performance

	Fuzzy sum of rows	Fuzzy synthetic extent	Relative weight $w'(S_i)$	Normalized weight $w(S_i)$
Personal factors	(2,845 ;3,577 ;4,615)	(0,125 ;0,204 ;0,342)	0,412	**0,182**
skills/abilities	(3,208 ;4,178 ;5,448)	(0,141 ;0,238 ;0,403)	0,565	**0,249**
vigilance	(4,925 ;6,689 ;8,568)	(0,217 ;0,381 ;0,634)	1,000	**0,441**
Motivations	(2,535 ;3,096 ;4,054)	(0,112 ;0,177 ;0,300)	0,288	**0,127**
	Sum of rows (13,513;17,539 ;22,685)			

Table 12: Evaluation of local priorities for sub-criteria of Job attributes

	Fuzzy sum of rows	Fuzzy synthetic extent	Relative weight $w'(S_i)$	Normalized weight $w(S_i)$
Criticality	(2,629 ;3,303 ;4,200)	(0,218; 0,343; 0,545)	0,769	**0,367**
Activity impact	(1,892 ;2,225 ;2,785)	(0,157; 0,231; 0,361)	0,329	**0,157**
Safety Impact	(3,192; 4,111; 5,053)	(0,265; 0,427; 0,655)	1,000	**0,477**
	Sum of rows (7,713; 9,639; 12,038)			

Table 13: Evaluation of local priorities for sub-criteria of Team attributes

	Fuzzy sum of rows	Fuzzy synthetic extent	Relative weight $w'(S_i)$	Normalized weight $w(S_i)$
Communication	(3,811; 5,096; 6,573)	(0,173; 0,300; 0,501)	1,000	**0,311**
Pattern of distribution	(2,313;4,178 ; 2,762)	(0,105; 0,163; 0,275)	0,424	**0,132**
Team experience	(3,512; 4,557; 5,919)	(0,160; 0,269; 0,452)	0,897	**0,279**
Global synergy	(3,472; 4,546; 5,877)	(0,158; 0,268; 0,448)	0,895	**0,278**
	Sum of rows (13,108;16,960;21,971)			

4.3.2. Calculation of priorities for alternatives

Similarly, the approximation of local priorities for alternatives are made depending to the degree of satisfaction to sub-criteria. A normalized weight is calculated for each alternative according to each sub-criterion and then the main criteria (Tables 14 to 16). Alternatives (teams) are ranked according to the estimation of global priorities presented in Table 17.

Table 14: Evaluation of alternatives according to sub-criteria of Individual performance

	Personal factors (0,182)	skills/ abilities (0,249)	Vigilance (0,441)	Motivations (0,127)	Priority Weight
Team 1	0,636	0,048	0,598	0,466	0,450
Team 2	0,255	0,302	0,294	0,332	0,294
Team 3	0,108	0,651	0,108	0,202	0,255

Table 15: Evaluation of alternatives according to sub-criteria of Job attributes

	Criticality (0 ,367)	Activity impact (0,157)	Safety Impact (0,477)	Priority Weight
Team 1	0,178	0,504	0,169	0,288
Team 2	0,398	0,332	0,252	0,277
Team 3	0,424	0,164	0,579	0,251

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Table 16: Evaluation of alternatives according to sub-criteria of Team attributes

	Communication (0,311)	Pattern of distribution (0,132)	Team experience (0,279)	Global synergy (0,278)	Priority Weight
Team 1	0,502	0,332	0,093	0,472	0,275
Team 2	0,130	0,294	0,275	0,160	0,239
Team 3	0,368	0,373	0,632	0,368	0,485

Table 17: Weighed sum evaluation for each alternative according to sub and main criteria

	Individual performance (0.313)	Job attributes (0,427)	Team attributes (0,260)	Priority weight	Rank
Team 1	0,450	0,288	0,275	0,336	1
Team 2	0,294	0,277	0,239	0,272	3
Team 3	0,255	0,251	0,485	0,313	2

5. CONCLUSION

The goal of this study is to provide an adequate Multi-Criteria Decision Making (MCDM) method to team selection in critical safety context. Our modeling of the TP as a combination of elements identified in SA theories and elements of the systemic approach of safety management could be a new start for team comprehension and analysis in ergonomics. The resolution of TP problem based on TP proposed model by fuzzy AHP is a novelty as well as for team cognition, for MCDM methods and for fuzzy logic. The numerical resolution, as detailed in the case study, shows that this way of measurement is a tangible approximation of a complex problem where many subjective components interfere. The proposed methodology is a basis of the applicability that can be adapted and modulated according to the context and the need of a firm. Based on this, an organization can define an adapted model as a tool of decision making to approach team work selection problem. This is encouraged by the availability of large choice of software tools that facilitate the numerical resolution.

The absence of correlation between criteria in the presented methodology may be a limitation of the FAHP application. Furthermore, the use of other methods for handling FAHP and ranking alternatives than extent analysis methodology as fuzzy entropy or another MCDM method can be advanced and discussed in further researches.

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