The relationship of team knowledge and team performance in high risk environment

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Abstract

As the popularity of team work have significantly increased in the last decades, several studies are focusing on the factors that influence the success of team work. One of these factors is team knowledge, in other words being on the same page regarding the team's task. In our study we focused on firefighter teams, how their perceived and actual team knowledge influence their performance during simple and complex tasks. Although our assumptions were not statistically significant, there are tendencies that show the relationship between knowledge types and performance. Limitations and further directions are introduced at the end of our paper.

Keywords: Team Mental Model, Team Knowledge Index, Team Performance

Team knowledge and high risk environment

The world of work has changed significantly in the last few decades. One of the most remarkable changes is the onset of team work. Teams are "distinguishable sets of two or more people who interact dynamically, interdependently and adaptively toward a common and valued goal, object or mission." (Cooke et al., 2000). As highlighted in this definition, team members are closely interdependent on each other, which indicates that their level of cooperation might have a crucial effect on how successfully they achieve their goal in an environment in which they continuously have to adapt their decisions and behavior to what the current situation requires. Several factors may be mentioned when trying to explain why team work is such a fashionable trend and why it is preferred by organizations. First of all, members of a team have the chance to share cognitive workload (Mathieu, et al., 2000; Hámornik & Juhász, 2010), thus making task completion significantly easier and faster, as well as reducing the risk of errors. Not only teams can share cognitive workload, but also they have a greater likelihood of coping with unexpected events (Levi, 2011; Soós & Juhász, 2010), thus increasing an organization's responsivity to various challenges, which may mean a great advantage for an organization in nowadays ever changing business environment.

Enjoying these advantages of team work, however, requires some pre-conditions to be fulfilled, otherwise the success of the team will undoubtedly lag behind. One of these critical pre-conditions is about the team having a shared and accurate knowledge about

key elements of teams' relevant environment (Mohammed & Dumville, 2001; Klimoski & Mohammed, 1994; Mohammed et al. 2000). In our study we chose to use the terms team mental model and team situational model to name the phenomena which explain how common knowledge between team members helps the team to perform. The concept of team mental model was developed to account for the fluid and implicit coordination in effective teams as well as how teams function in complex, ambiguous situations. Team mental model is defined as team members' shared and organized understanding of knowledge about key elements of teams' relevant environment (Mohammed & Dumville, 2001; Klimoski & Mohammed, 1994; Mohammed et al. 2000). This refers to the collective task- and team-relevant knowledge that members bring to a situation, and it is acquired by formal training, experience and team discussions. The content of team mental model can include knowledge relevant to teamwork (e.g. the roles and responsibilities of team members). This type of knowledge is called the team-related team mental model. The team mental model can also include knowledge relevant to the task and goal itself (e.g. understanding of the task and strategies), which is called the task-related team mental model. As mentioned before, the team mental model of a team should not only be shared by all team members, it also has to be accurate and correct. It is not difficult to imagine how a team would perform with an incorrect knowledge about a task, even if it would be shared by all members.

Being on the same page is a very important predictor of team performance, especially for teams that work in high-risk, dynamic environments, since the members often do not have time for explicit communication during task execution. High risk environments are defined as environments in which there is a more than normal likelihood of damage to one's own health or even loss of life, the health or life of others or to material property (Dietrich, Childress, 2004). Teams working in such environments consist of highly trained individuals, with fairly strict protocols to follow in most scenarios they are envisioned to find themselves in. However, when it comes to non-routine situations, they have to adapt their protocol and behaviors to the current situation. These groups are expected to interpret information from multiple systems and to make decisions in non-routine, time-pressured, high-workload situations (Waller, 2004). The adaptation of these teams to abnormal situations is critical, since the way they handle the problem and the decisions they make might have a crucial influence on human lives and/or the environment.

We hypothesize that the quality of teams' team knowledge (accuracy and sharedness) will have an influence on how teams perform task execution. Furthermore, it is reasonable to assume that in a more complex situation, the importance of high quality team knowledge will increase. Last but not least, we are also curious if the perceived level of team knowledge (not the actual) plays a role in team performance, as well as how perceived and actual team knowledge are related to each other.

Methodology

To test our hypotheses, we collaborated with six fire fighter teams working for the Nuclear Power Plant in Hungary. Each of the teams consisted of seven fire fighters (a signalman, the head of the team, a fire truck driver and two pairs of fire fighters). According to our research design, team members filled out paper pencil tests at the beginning of the research session, assessing their perceived and actual level of team knowledge. After the paper-pencil tests, teams were introduced to two different simulated scenarios which they had to solve as they were real situations. One of them was a simple, routine task while the second one was a more complex situation with numerous

unexpected events. Teams were video recorded from 4 different angles during simple and complex task execution.

Perceived Team Mental Model

To measure how teams see their own level of team knowledge, its accuracy and sharedness, a questionnaire was created in which team members had to mark their level of agreement with each statements by using a 1-10 Likert-scale. The questionnaire consisted of items from other authors' previous studies (Solansky, 2008; Anderson & West, 1996; Gevers, et al., 2008), as well as items created by us, specifically for this research design. Items focused on how team members see the sharedness of their knowledge regarding team roles, the task itself and time-related aspects of task execution. Altogether, the questionnaire consisted of 13 items. Example items are *"The members of our team think in the same way regarding the execution of a task." "We all possess the same knowledge regarding work-related rules and protocols."*. By averaging the answers of team members, we created one single measure which is the average level of a team's knowledge (it's accuracy and sharedness).

Actual Team Mental Model

To measure team members actual team knowledge, teams had to read a professional scenario and answer multiple choice questions related to it. The scenario was created in collaboration with an expert team of fire fighters in order to maintain professional credibility. The task consisted of a fire at the -2,10 level of the second block and a presumably injured person who attempted to extinguish the fire but did not return. Example item was *"what is the signalman first supposed to do after the alert?" For each of the 8 questions there were four choices (A, B, C, D) and only one of them was correct.* Similar to the perceived team mental model, questions were focusing on team members knowledge regarding the task itself, the team members and their roles and well as time-related aspects. By calculating the ratio of correct answers within one team we gained an understanding of the level of accurate team knowledge. However, as we highlighted in the literature review, accuracy or sharedness of a knowledge are not a representative and correct measure without each other. We needed to find a measure that is able to handle accuracy and similarity at the same time.

Let us assume that there is a team with 10 team members having to answer a multiple choice question with four possible choices. Calculating the ratio of correct responses is relatively easy, we only have to divide the number of team members who answered correctly by the number of all the team members. In the case of 7 correctly answering team members, we can be sure that 70% of the team members answered in the same and correct way. However, at this point we do not know much about the remaining 3 team members, especially if they all chose another –unfortunately wrong- option or all of them chose different and wrong options. The best case scenario is obviously when all the team members answer correctly, since it means that they have an accurate and shared knowledge of the task. A less desired alternative is when most of the team members answer correctly, and some other team members answer in the same but incorrect way, since it means that the whole knowledge of the team is fragmented into two parts, and only one of them is correct. The worst case scenario is if there is a group of team members giving the same and correct answer, but the rest of the team members give answers that are not only wrong but different from each other, since it means that the knowledge is not only incorrect, but very fragmented as well.

Following this logic, we created "Team Knowledge Index" which is able to handle accuracy and similarity of team knowledge at the same time:

$$TKI_i = \frac{RCR_i}{F_i} * 100$$

where:

- RCR_i is the ratio of correct responses within the team for the i^{th} question (the number of team members giving correct answers divided by the total number of team members). The value of RCR_i can vary from 0 to 1, 0 when none of the team members give correct answer, and 1 if all the team members answer correctly.
- F_i *is* the number of answer fragments for the i^{th} question (the number of different answers given by team members for the same question). The value of F_i can vary from 1 (when all the team members answer in the same, correct way) to the maximum number of answer choices (in the case of a 4 choices test, the maximum number of F_i will be 4).

There is some standard, constant relationship in the TKI_i equation, namely:

- if RCR_i= n/n (it equals to 1), then F_i will be 1.
- if RCR_i= n-1/n, then F_i will be 2.

We calculated this index for each of the four questions, then by averaging them, we created one single measure for the actual team mental model.

Video recordings – simple and complex scenario

After completing the paper-pencil questionnaires, teams were introduced first to a simple, then to a more complex simulated scenario which they had to solve as they were real situations. In order to assure that the scenarios were professionally correct, we included and expert to create these situations. We recorded each teams and each scenario from four camera setups. One camera recorded the signal man, one recorded the head of the team, and two cameras recorded the two pairs during task execution.

The simple situation consisted of the following, simulated scenario: a fire broke out in the warehouse of the fire station. The extent of the fire was approximately 30 square meters, and there was no information of any individuals being injured or in danger, neither of explosive materials near the fire. This is considered a fairly simple situation which can be solved based on fire fighters' already existing routine, experience and knowledge.

As opposed to that, in the complex situation, the fire broke out in the bunker of the nuclear power plant. One person is assumed to be injured or in danger, who did not return after attempting to extinguish the fire. In addition, there is a gas bottle within the building which is considered as highly explosive. As the fire fighters arrive at the bunker, they realize that there is an iron bar blocking the entrance which they have to cut and remove to be able to enter the building. Before entering, each member of the two pairs receive a blindfold on their eyes, imitating a massive smoke, thus decreasing fire fighters' power of vision. There are two more unexpected events they have to adapt: first, the head of the team gets injured, and the fire truck drive has to take over the radio communication instead of him. Second, the entrance which they used crashes in, therefore fire fighters have to find the emergency exit to escape the building. Furthermore, radio communication within the bunker is hampered, consequently, communication between the whole team is very challenging.

Table 1 – Comparison of simple and complex situation

	Simple task	Complex task
location	already known	unknown
size of location	small	big
complexity of location	simple, one large area, few equipment	complex, several small rooms furnished
time pressure	low	high
communication	easy	difficult
unexpected events	none	three unexpected events: iron bar, the head of the team gets injured, the entrance crashes in
visibility	high	low
task complexity	simple task, routine task execution	complex – fire, injured person and a highly explosive gas bottle

Performance measure

Performance measures were based on the video recordings. First, -in order to make comparison of the teams easier – we separated both simple and complex situations into phases, and cut the videos according to them. When creating the competences to be evaluated, we used a bottom-up, "naked eye" technique, which means that we did not use previous preconceptions about the competences. Instead, by watching the videos we were making notes of behavioural markers that were observable, perceptible to the naked eye. Only after this phase we started to categorize these markers and name them. This is how the competences that experts had to evaluate were developed. In order to create objective, professionally correct measures of the teams' performance, a team of three experts (senior fire fighters) were asked to rate the performance of the fire fighters in the simple and complex situations, based on the video recordings. Altogether, more than 40 hours were spent on evaluating these teams' performance in the simple and complex situation. After watching the video recordings, experts rated the competences individually, then they had to reach a consensus regarding the final rating. Experts evaluated each team member separately, as well as the team as a whole. At this stage of our research, we only focus on performance of the teams. Experts rated the performance of the team from different aspects (motivation, coordination, dynamism, situation awareness, etc.) on a 0-6 scale, where they gave 0 if the behaviour or competence were not observable, 1 if the behaviour or competence was not at all typical for the team and 6 if the competence, or behaviour was very typical for the team. By averaging the final rating of the competences, we created one single performance measure for each team and for both simple and complex tasks.

Results

As the first step of the analysis we took a look at the average values that we created, if there are any observable tendencies that suggest a further statistical analysis of the data. Average values of each team across all the variables introduced before (perceived and actual team mental model, performance rating in the simple and complex situation)

Table 2 – Averages of measures (perceived and actual TMM, simple and complex performance

	Perceived Team Mental Model (1-10)	Actual Team Mental Model (0-100)	Performance in Simple Situation (0-6)	Performance in Complex Situation (0-6)
A1	7.54	39.33	2.83	2.55
A2	7.65	45.55	4.50	3.82
B1	8.08	62.83	4.42	4.11
B2	7.77	47.31	3.42	2.71
C1	7.69	48.75	5.58	5.81
C2	7.98	50.88	5.58	4.01

As it can be seen from Table 2., there seems to be a relationship between the two forms of team mental model, as well as the two performance ratings, however it is still unclear whether perceived or actual TMM has an influence on performance ratings.

As the second step of the analysis, we attempted to support our assumptions by statistical methods, although we were aware of the imitations of these results due to our very small sample size. Pearson correlation showed a significant, strong, positive relationship between perceived and actual team mental models ($r=0.913$; $p=0.011$) which indicates that these teams possess a realistic understanding of their knowledge and competences as a team; those who perceived the team's knowledge higher also scored significantly higher on the actual knowledge test. Pearson correlation also showed a significant, positive relationship between performance ratings of the simple and complex situations ($r=0.63$; $p=0.27$), furthermore, according to paired sample t-test, there is a statistically tendentious difference between the two performances ($t=2.26$; $p=0.74$), performance in the complex situation was rated remarkably lower than in the simple situation. It indicates two possible reasons. Having found a tendentious difference between the simple and complex performance ratings indicates that the complex situation was indeed more difficult to execute, however, these differences should not have been statistically significant in teams who scored higher in on the perceived or actual team mental model scale. Furthermore, it also might indicate, that the expert team's evaluation procedure was learned, in a way that first, when evaluating the simple situation, they gained an overall impression of the teams and these impressions influenced them when evaluating the same teams in complex situations. Statistical analysis however did not show significant correlation between perceived team mental model and simple ($r=0.443$; $p=0.379$) or complex performance ratings ($r=0.217$; $p=0.680$), neither did it in case of the actual team mental model and simple performance ratings ($r=0,394$; $p=0,431$) or complex performance ratings ($r=0,394$; $p=0.439$).

Conclusion

Nowadays team work is one of the most fashionable and preferred way of task execution, regardless of the sector, the professional field or the nature of the task itself. Working in teams has many advantages that – if well-organized- can bring competitive advantage to an organization. Team work allows team members to share cognitive workload, to be more innovative and creative than members individually would be, thus allows the team to reach a higher performance than an individual team member; also it serves as the basis for a flexible and quick adaptation to the ever changing environment (economical, physical) that the organization is surrounded by. Last but not least, team members are important resources of social support to their own team members which is an important

mediator in work satisfaction. Although preferred and fashionable, the success of team work is not evident or guaranteed without taking some very important pre-conditions into consideration. One of these pre-conditions is team knowledge, in other words, it is crucial for team members "to be on the same page", regarding the task, their roles and time-related factors (deadlines, pacing and speed). A team's Team Mental Model is one of the most popular theoretical approach that focuses on how these knowledge structures are organized within the team. According to this model, team knowledge has two very important aspects: knowledge similarity and knowledge accuracy. While similarity refers to the extent to which knowledge is shared between team members, in other words, the extent to which the team thinks in a similar way of a task and its details. Accuracy however, refers to extent to which team's way of thinking is correct. In other words, it is not enough to have a shared knowledge between members, this knowledge has to be shared *and* correct at the same time in order to enable the team to efficiently execute a task. In order to be able to measure team knowledge including similarity and accuracy aspects as well, we created a "Team Knowledge Index" (TKI_i), which seems to be an efficient a logical measure of team knowledge in cases when the tool for measuring is multiple choice questionnaire.

A shared and accurate knowledge is even more important in cases when there is a more than normal likelihood of the team members to risk their own lives, other people's lives or damage material properties. These teams work in high risk environment, consist of highly trained individuals where every day work is based on strict rules and protocols. Furthermore, working in high risk environment usually means a fairly heavy workload and a significant time pressure as well.

In our research project we focus on fire fighter teams working for the nuclear power plant in Hungary. At this stage of our project we were curious whether perceived (how team members think about) and actual (how it is in reality) team mental models are in any connection with team performance. We also aimed to explore whether perceived and actual team mental models are related to each other. We also assumed that the complexity of the situation itself will also have an influence on the extent team mental models need to be used in action. In other words, in a more complex situation, a better performing team will have a higher quality team mental model, thus the relationship between team mental models and performance will be stronger in the case of a complex situation. Our sample was six different teams who at first filled out questionnaires measuring perceived and actual team mental models, then they were exposed to a simple and a complex situation in which their activity was video recorded. Video recordings were analysed and evaluated by experts, this is how performance measures were created.

According to the results, perceived and actual team mental models are indeed in positive relationship with each other, indicating that teams do possess a realistic perception or understanding of the quality of their own team knowledge. Performance ratings in the complex situation were tendentiously lower than in the simple situation which indicates that the complex situation was indeed more difficult to solve. The positive relationship might indicate two reasons behind the number: either the performance difference between all the six teams was constant, in other words, a higher performing team in the simple situation also performed higher in the complex situation because of its skills. The other possible case is that the experts' ratings were constant, in other words, they have learned an overall impression about the teams in the simple situation and this impression influenced their ratings during the complex situation. Last but not least, none of the team mental models showed a relationship with performance in simple or complex performance. To account for this result, some explanations need to be considered: first of all, the sample size in our research is far behind being statistically relevant or reliable. In

addition, at this, very early stage of the whole research project, we have worked with global, average values. After watching video recordings, the experts gave separate performance ratings to each roles within the team (signalman, the head of the team, 1st and 2nd pair of fire fighters), however, at this point we only analysed the global ratings for the team as a whole. It is possible that the relationship between team mental model and performance ratings is only typical for one, separated role within the team (for example, the head of the team who needs to create and communicate the strategy that the whole team has to follow). By analysing average values, at this point we also created average values for performance ratings of the teams, however, experts originally evaluated numerous aspects of team performance (dynamism, motivation, coordination, situation awareness, etc.). It is possible that the relationship between team mental models and performance is specified to one of these aspects, and by analysing them separately, our assumption would gain more support. The third reason is related to team mental models. In our research project we focus three different forms of team mental models? one related to the task itself, one related to the team (roles, and responsibilities), and one related to time (deadlines, sequence of task execution, etc.). It is possible that not all aspects of team mental models have a connection with performance ratings, and fire fighter teams' performance is specifically related to one or two aspects of the team's team mental model. In the near future, our plan is to explore these possible connections in detail.

Limitations for future research

Last but not least, there are some limitations of our research project to take into consideration for future research. As mentioned before, sample size is relatively small for statistical analysis, although it fits our plan, that was to test our hypothesis with real teams working in high risk environment, instead of simulating the same conditions with a larger sample of university students. Second, our experts were senior fire fighters of the same fire departments, therefore, it is possible that their preconceptions or previous knowledge about these teams influenced their ratings. Even if this was not the case, the way they evaluated the teams in the first, simple situation might have affected their rating style in the complex situation. An efficient solution could be if evaluating session of the simple and complex situations would be separated from each other in time.

Research on team work is a very fruitful and exciting field of psychology and management sciences, with many scientific connections waiting to be explored in the future. Our aim was to shed a light specifically on teams working in high risk environment, to gain a better understanding how these teams' work can be smoother, and even more efficient in the future, as well as to explore the ways team knowledge influence their efficiency. By creating "Team Knowledge Index" we aimed to contribute to the measurement of team knowledge, hoping that this Index will be used and further developed by other researchers we might have inspired with our work.

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