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Let's Add Highly Stressed People to the Cyber-Physical-Social System

Mare Teichmann, Johannes Ehala, Jaanus Kaugerand, Merik Meriste, and Kalev Rannat

Laboratory for Proactive Technologies, Tallinn University of Technology, Tallinn, Estonia
jaanus.kaugerand@taltech.ee

Abstract

We discuss the negative impact of high levels of stress on a person's cognitive situation awareness and management capability. This is a critical aspect to consider when designing people-centered Cyber-Physical-Social Systems (CPSS). High levels of stress can negatively affect how people perceive and interpret information, resulting in an inability to understand the situation adequately and inadequate decision-making. The paper highlights that high levels of stress can also make it challenging for people to follow rules and regulations in crises situations. We discuss several aspects of how CPSS could help people in crisis situations to better follow rules and regulations.

1 Introduction

The advancement of technology has led embedded systems to become more and more pervasive and interconnected. For almost two decades now we talk about cyber-physical systems – systems connecting physical processes with digital monitoring and control. These systems have become extensive, complex, interconnected with humans and influential in our lives so much so, that the term has since been augmented to include the social aspect. Cyber-physical-social systems (CPSS) are all around and encompassing, intended to improve our lives, increase safety and performance of complex processes, facilitate operation of complex machinery, monitor and control dynamic processes and support disaster relief and recovery to name just a few applications. We chose to focus on CPSS designed for handling complex dynamic systems (e.g. piloting aircraft) and CPSS designed to help manage crisis situations (e.g. technology supporting incident response teams). Both these situations, complex, dynamic and crisis, are high stress environments for the people embroiled in them (e.g. system operators, incident response teams and ordinary people in crisis situations). We discuss how stress affects people in these situations and what implications this has for the design of CPSS. Specifically, we argue towards a more people centered approach to CPSS design, one that puts the well-being of people at the center of the design problem. We suggest that, if stress is better managed in CPSS, this could have a significant positive effect on the overall performance of the CPSS and the satisfaction of the individuals involved.

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In order to understand how stress becomes a factor we utilize the notions of situation awareness and situation management. Both are integral activities and valuable competences for people operating complex dynamic systems and managing or surviving crisis situations. Situation awareness is described as the cognitive ability of humans and artificial agents to gather relevant information, comprehend its meaning and anticipate possible future scenarios for the purpose of better decision making and handling of situations [9]. Situation management is a broader term involving situation awareness as well as decision making and action. It additionally comprises higher cognitive activities such as learning, problem solving and adaption [18]. In many fields (e.g. aviation, cyber-security, intelligent transportation, military command and control, emergency response) one of the main purposes of CPSS is to augment and enhance operator situation awareness and improve situation management.

Situation awareness and management both encompass various cognitive activities (e.g. perception, attention, pattern recognition, working memory, reasoning, intuition, etc.) [2]. In order to design CPSS that better help humans in their tasks, it is important to consider the possible factors affecting these cognitive processes. We identify stress as a significant factor and focus specifically on high levels of stress and its effect on cognitive situation awareness and management (CSAM). We discuss how stress affects CSAM of operators of complex dynamic situations and on CSAM of people managing or trying to survive crisis situations. We identify several stressors for people in these situations and propose alleviating measures to deal with them. Finally we discuss the implications of our findings for CPSS design.

Section 2 discusses how stress affects CSAM. Section 3 identifies overall levels of stress in society. Section 4 evaluates rule creation approaches and peoples motivation to follow rules. Section 5 discusses stress relief and how CPSS can help alleviate stress.

2 EFFECT OF STRESS ON CSAM

Stress is a well studied phenomenon. It can be defined as a state of worry, strain or mental tension caused by a difficult situation [14, 4]. Stress refers to a person's physiological or/and psychological response to events and situations. There are internal and external sources of stress, referred to as stressors, that typically manifest together in some combination (for example dealing with uncertainty, complexity of technology, time pressure, computer user's hassles etc.). Stress causes the release of hormones such as cortisol and adrenaline, which can increase heart rate, blood pressure and breathing, preparing the body for a "fight or flight" response. Although some stress is useful for acute interruptions, helping us respond quickly to immediate threats and challenges, too high levels of stress can lead to a narrowing of attention and a reduced ability to process complex information. This can result in tunnel vision, where a person focuses on one aspect of a situation while ignoring other important information [6]. Prolonged exposure to stress can lead to chronic stress that in turn has additional negative effects on cognitive functioning.

The impact of stress to CSAM is significant especially in regard to CPSS and complex, dynamic and crisis situations for two reasons. First, complex dynamic and crisis situations are stressful environments such that stress of operators and people involved is almost certainly to be expected. Second, one of the main methods of how CPSS help people manage complex dynamic and crisis situations is by improving the CSAM abilities of operators and other people involved. It is clear that we need good understanding of the effects of stress to CSAM to better design CPSS to help operators and people in difficult situations. The following is a review of the most common effects stress has on the cognitive capabilities of a person and the consequences this has to CSAM.

A number of research has shown that high levels of stress can impair various cognitive processes important to situation awareness and decision making. For example, stress can cause problems with perception [31] and can lead to a decrease in attention and concentration [30, 5]. This hinders a persons ability to take in available information and causes them to miss important details [22, 37]. A failure to notice changes in the environment leads to poor situation awareness and inadequate decisions.

Stress can also impair working memory [10, 20], making remembering and recalling multiple pieces of information at once harder, which in turn hinders decision-making [3, 32]. Failure to remember important details leads to errors in judgment and a lack of situation awareness [36]. An inability to focus, makes it harder to weigh the pros and cons of different options when making a decision. Mistakes in processing and interpreting information [34] lead to a reduced ability to weigh options and consider potential consequences. Stress impairs judgment, leads to poor choices and an failure to manage the situations effectively [1, 16].

Stress makes it harder for people to manage their emotions leading to emotional and inadequate reactions [27]. This can lead to a sense of urgency or panic, which leads to impulsive decisions [22, 37], lack of perspective and impulsive behavior [45]. Stress can also induce fatigue [35], cognitive overload [29], cognitive impairment [7] and unawareness [46].

Communication and cooperation are another important aspect of effective situation management. High levels of stress can make it difficult for individuals to communicate clearly and effectively with one another. This leads to misunderstandings and confusion, making it harder for individuals to make sound decisions [15].

Considering the multifaceted effect of stress on people's cognitive abilities it is critical to counterbalance potential stressors related to complex, dynamic and crisis situations. This issue should be addressed in CPSS design, but it is also important for people to learn how to manage their stress levels themselves. This can be done throughout stress reduction techniques, for example deep breathing exercises, meditation, mindfulness practices, physical activity as well as seeking support from others when needed. A well designed CPSS should assist in these activities. Managing the stress level of people involved will improve their CSAM abilities and consequently help them make better decisions in high-pressure situations.

3 STRESS IN SOCIETY

Stress is a growing health issue in today's society not limited to only operators of complex dynamic systems and people in crisis situations. We highlight the magnitude of stress in society, and consequently imply its significance to CPSS design, by reviewing several empirical surveys conducted in Estonia that included the measurement of stress. First, we present the stress levels of the general population of Estonia and identify a risk group within Estonia's population. We then demonstrate that the stress level of the risk group is chronic and is not necessarily related to any specific single event (such as COVID pandemic or war in Ukraine). We show that the risk group reports more mental health problems than the general population and finally relate various stress symptoms with stress.

In our first analysis sixteen professionally conducted surveys [40, 42] were analyzed with 1,251 - 1,509 respondents participating in each survey. The samples of all surveys were representative of the Estonian population, i.e. the samples were representative in terms of age, gender and nationality of the respondents. The sample size of each survey was about 0.1 per cent of the Estonian population. The research question posed to participants, as well as the response scale for answers, was identical in all studies. The question was, "Have you felt stressed or been under the pressure within the last 30 days?", and the answers range was from "Don't

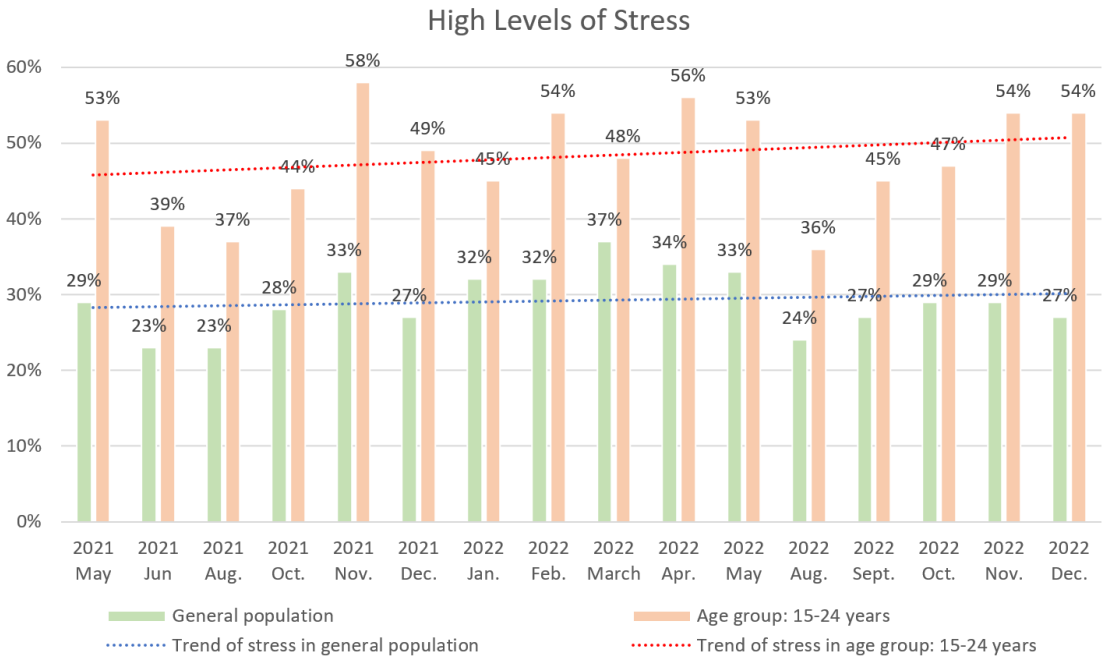

Figure 1: Share of people reporting high levels of stress. Survey commissioned by Estonian Government Office [40, 42].

know" to "Yes, very frequently". For our analysis of the general level of stress in society we considered only the answers "Yes, very frequently" and "Yes, frequently" (in response to the question about stress). As can be seen from Fig. 1 close to 30% of the general population show high levels of stress. Reviewing the data of each age group separately, we identified the age group 15 - 24 years as a risk group with high stress levels in Estonia. Survey results indicate that an average of 40% - 50% of 15-24-year-olds experience high levels of stress (Fig. 1).

The age group 15-24-year-olds has developed permanent high levels of stress, which has not risen suddenly due to some extreme event (e.g., war in Ukraine), but has developed over a longer period of time. According to our understanding, chronic stress is the physiological and/or psychological response to continuous long-term stressors. We can clearly see the development of chronic stress among the 15-24-year-old risk group in Estonia. There is a heightened risk of developing mental and physical health problems, if measures to reduce the high level stress are not taken in this risk group. The ability to handle complex or crisis situations will be a challenge for people in this age group.

Our second analyses found that people in the risk group suffer more frequently from mental health problems than the the general population of Estonia. In regularly conducted public opinion surveys [41] respondents were presented with a list of 18 problems or ailments and asked to rate how much these problems had bothered them during the last four weeks. The statements measured different psychopathological issues grouped into three categories: 1) depression or mood disorders, 2) anxiety and 3) asthenia or mental exhaustion. Based on the assessments given to the statements a field score was calculated for each respondent that determined whether the respondent might exhibit any given mental health problems from the three categories. The findings show that the risk group 15-24-year-olds report higher degrees of psychopathological

symptoms, particularly symptoms of asthenia, than the general population (Fig. 2).

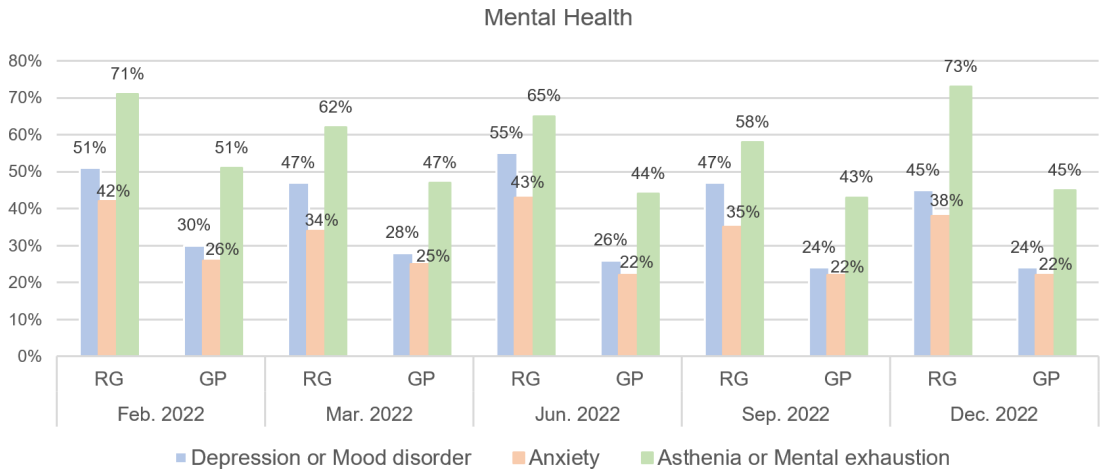

Figure 2: Comparison of mental health issues in general population (GP) and in risk group (RG). Survey commissioned by Estonian Government Office [41].

Our third, empirical research from 2018–2021 (participants n=2502) suggest significant correlations between different symptoms of stress and high levels of stress (Table 1). The methodology used in the study, including the validity and reliability of the OPSTI test, have been presented in previous works [38], [39]. OPSTI test consists of 60 items with six-point Likert-type forced responses ranging from: "Never / Very infrequently" to "Always / Very frequently". Results show that those people who confirmed high levels of stress, declared also sleep problems (36% responds "Frequently" or "Very frequently"), anxiety (33%), exhaustion (21%), memory problems (20%), and attention and concentration problems (17%). Memory problems and attention and concentration problems directly affect peoples CSAM abilities, while exhaustion, anxiety and sleeping problems can cause emotional reactions, cloud judgment and lead to biased decision making.

Table 1: Correlations between high levels of stress and symptoms of stress (studies between 2018 and 2021; n=2502)

Symptoms of stress	Correlation with high levels of stress
Anxiety	0.42
Exhaustion	0.56
Attention and concentration problems	0.37
Memory problems	0.43
Sleep problems	0.48

All correlations presented were significant at $p < 0.05$

Stress appears to be a growing (at least in certain age groups) concern in society. It is most certainly a concern for operators of complex, dynamic systems and people in crisis situations.

It would be beneficial if CPSS could address this issue and possibly try to alleviate its impact on peoples CSAM abilities.

4 FOLLOWING RULES IN CRISIS SITUATIONS

In stressful situations the possible personal danger, the high stakes involved, the speed and amount of information available, the challenge of comprehension of perceived information, and other factors can easily overwhelm people and cause cognitive overload and impairment. This leads to people freezing or locking up, becoming incapable of making decisions and taking action. However, doing nothing in crisis situations or when operating complex, dynamic systems can often be more harmful than doing at least something, even if the action is sub-optimal.

Various rules, procedures and guidelines are usually developed for crisis management, for the operation of complex systems and for surviving crisis situations. Rules are intended to help people overcome their impairment and make decisions and take action. Here we consider two sets of rules associated with CPSS that help people manage complex, dynamic and crisis situations. First, there are rules that stem from external sources such as laws, government regulations, rules of public and private organizations etc., and are imposed by the CPSS. Second, there are rules that the CPSS itself introduces. These might be restrictions regarding the operation of CPSS components, instructions regarding interaction between components of CPSS, correct procedures for various activities, constraints that stem from the construction and functioning of the CPSS, etc. For example pilots have quick reference handbooks (and an electronic flight bag) for various flight and aircraft conditions, incident response teams have their appropriate standard operating procedures, the general public has guidelines such as "stay indoors" in case of danger, etc.

Due to the nature of complex, dynamic and crisis situations, the rules and procedures will be directed at people with high levels of stress. Under high levels of stress it can be difficult for people to understand and follow rules and procedures, even if they are willing to do so, for a few reasons. First, stress affects a person's ability to concentrate, make decisions, and control emotions, which leads to impulsive and irrational behavior that can lead people to break rules and regulations. Second, stress can cause people to prioritize short-term gains over long-term goals. This can lead to people taking shortcuts or breaking the rules to get immediate stress relief.

There are a number of factors that influence how well people follow rules and procedures under high levels of stress: the clarity and simplicity of the rules, the importance of rules to the person, the consequences of breaking the rules, proactive training and preparation, social pressure, etc. In this section we discuss a persons motivation to follow rules and how rules can be made in a way that people are more motivated to follow them.

4.1 The Fitting Dilemma

The idea that people are more likely to voluntarily follow rules when they are involved in the design of the rules is not new [21], [23]. Developing this idea further, we suggest that, in practice, there exists a fitting dilemma, the solution of which has importance for stressful crisis situations. The fitting dilemma (Fig. 3) asks whether rules should be designed to suite people or whether people should adapt to predesigned rules.

Fitting a man to the rules and regulations generally refers to the process that aims to make an individual person conform to the norms, values, and expectations of a particular group or society. This process involves teaching or training people to follow rules designed to govern

their behavior in a given environment or situation. It may involve instilling certain values or beliefs that are seen as important within a particular culture or community. In general, fitting a person to the rules and regulations is the management-centered view (top-down design) in terms of the other party (e.g. citizens). In some cases, the process of fitting a man to the rules and regulations is beneficial, as it can help to increase harmony and cooperation between individuals or groups. However, in other cases it is a restrictive and oppressive process as it can limit peoples' ability to express themselves or pursue their own goals and aspirations.

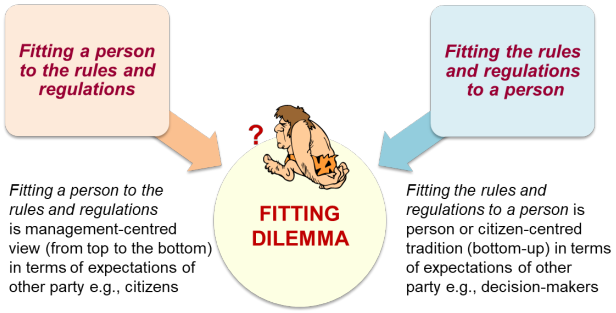

Figure 3: The Fitting Dilemma

Fitting the rules and regulations to a person on the other hand is a person-centered view (bottom-up design) in terms of expectation of the other party (e.g. decision-makers). Fitting the rules and regulations to the man refers to the idea that rules and regulations should be designed to fit the needs and characteristics of the people who are subject to them, rather than expecting people to conform to a pre-existing set of rules and regulations. This approach recognizes that people have different backgrounds, experiences, and needs, and that a "one-size-fits-all" approach to rules and regulations may not be appropriate or effective in all cases. Moreover, the rules themselves might be outdated, incomplete, or impossible to follow. Instead, rules and regulations should be designed to be flexible and adaptable, taking into account the unique circumstances and needs of the people they are meant to serve. CPSS that help people manage stressful situations is an ideal tool for this type of personalized and specific rule generation and presentation.

4.2 Motivation to Follow Rules

According to motivation theories as well as empirical studies [24], motivation can be both intrinsic and extrinsic. People's motivation is higher if they act according to their inner desires and beliefs (intrinsic motivation) rather than external stimuli or obligations (extrinsic motivation).

Intrinsic motivation "I want to do" comes from an internal desire or interest to engage in a specific activity or goal. It is driven by personal choices and pleasure. When a person says "I want to do" they expresses a strong sense of personal agency and autonomy. There is a big difference between whether a person wants to follow rules or whether a person must follow rules. In terms of self-motivation, this means that people prefer to do what they want to do, and are not overly enthusiastic about following rules they are forced to or must follow. The idea that people with high self-motivation are more likely to follow rules even in stressful situations, is supported by both, classical views about human motivation [43] and also by more recent research [26].

Extrinsic motivation, on the other hand, refers to the desire to engage in an activity or task

that results from external incentives such as money, praise, recognition or fear of punishment. Extrinsic motivation is driven by a sense of duty, of responsibility and accountability. The feeling "I must do" is different from "I want to do" as it expresses obligation rather than personal interest or desire. This type of motivation is often associated with a pressing need to meet external standards or requirements. It is clear that people prefer to do what they like rather than what they have to do.

Combining the fitting dilemma and motivation theory, it is clear that getting people to adhere to rules and regulations and behave in a certain way is much easier if the person is self-motivated to follow the rules. This is especially important in crisis situations because it is much more difficult getting a stressed person to do what they do not want to do using only external motivators such as praise, reward or fear. We therefore make several suggestions about rule making that should improve peoples ability to better handle crisis situations as well as manage complex, dynamic systems.

5 MANAGING STRESS IN CPSS

During stressful crisis and complex, dynamic situations, it is quite common to be overwhelmed and feel strain and stress. However, it is essential to manage ones high levels of stress to prevent it from affecting ones situation awareness and management capabilities to properly deal with the situation. Reducing high stress levels of people in stressful situations is not easy, but we feel there are ways CPSS can help people in this regard.

In many fields calls to make CPSS design human-centered again can be heard [28, 44, 8]. We suggest that in general CPSS user experience should become more personalized and inclusive. There are a several ways this can directly help cope with stress. First, people should be more involved in the design of the rules, procedures, guidelines and regulations imposed by and used in the CPSS. Of course laws and external regulations cannot be entirely changed, but the way they are implemented and enforced can be made more personal. There are also rules and procedures that are inherent to a CPSS, that stem from the structure and design of the system. Consider for example navigation applications on smartphones and the larger CPSS that they compose. Navigation applications provide live traffic updates about routs, congestion, travel times etc. This feature stems from the overall structure and functionality of the CPSS, i.e. live traffic information is generated by all users and the system as a whole. This leads to an inherent rule – users need to allow the navigation app to track their position in order for the live updates functionality to be available in the system.

Our first suggestion is to allow customization of rules and procedures where possible. This should not be limited to only modifying user interfaces of CPSS, but also enable users to personalize structural and behavioral aspects of the CPSS. By allowing users to make functional changes to CPSS they also take responsibility for their decisions. Studies have shown that this increases peoples self-motivation, increases personal autonomy and subsequently reduces stress [25], [19]. An additional benefit is that people are more committed to following the rules, if they feel they are included in the creation process.

Another principle about rule and regulation creation is to keep the rules simple, short and understandable (i.e. less bureaucratic language). Empirical findings support the idea that overly complicated or difficult-to-understand rules may make it difficult for individuals to follow them, especially in stressful situations [47], [11], [13]. As the second suggestion, we believe that this principle should also be included in CPSS design, especially for operation of complex, dynamic systems and crisis management.

Our third suggestion is that even during stressful crisis situations it is possible to use fast-acting stress relief techniques – for example, deep breathing, muscle relaxation, visualization, meditation, physical exercising or walking, talking etc. However people typically do not know about these techniques or how to apply them. They also may not be aware of their own stress levels. Here technology has an opportunity to aid users by monitoring their health and activity, recommending stress relief techniques and providing instructions to use them.

Taking personalization one step further, we suggest extensive monitoring of CPSS constituents (both human and artificial agents) with the goal of automatic assessment of their status. In many fields this idea is known as creating a digital twin of the monitored object (or agent) [17, 33]. The digital twin encapsulates the current state and state history of the object and enables simulating or predicting possible future states for the object. The benefit of the digital twin is to be able to proactively interfere in the operation of the monitored object to prevent undesired behavior.

Another benefit is enabling appropriate representations of CPSS constituents to be shared among the CPSS. Since CPSS are comprised of numerous heterogeneous artificial and human agents that are often geographically and temporally separated it is difficult for the agents to assess the disposition or "mood" of their interaction partners. This makes cooperation and communication difficult especially when intent needs to be communicated or assessed. Having up to date digital representations allows to tackle this issue and even deal with trust in CPSS [12]. Regarding stress management, a personalized, digital-twin-like approach would enable to regulate how certain rules, procedures and restrictions are imposed on people. Giving a person the option to choose between alternatives is the needed inclusive approach in CPSS that empowers self-motivation, reduces stress and improves commitment.

6 Conclusions

The rapid growth of CPSS has had its side-effects and people are still adapting to the new pervasive, all-encompassing systems. We have focused on high levels of stress as an issue in CPSS, and have pointed out that stress has a significant effect on people's CSAM abilities within CPSS. This is problematic for operation of complex, dynamic systems and managing crisis situations. Since CPSS are intended to help people in these situations we suggest focusing more on stress and its impact in CPSS. We propose several alleviating measures to counter stress in CPSS, such as involving people into the rule creation process, keeping rules simple, providing stress relief techniques and providing personalized health and activity monitoring. Managing stress better for humans in CPSS will enhance decision-making abilities and overall CSAM of individuals in stressful situations.

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