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Understanding Fire and Rescue Service Practices Through Problems and Problem-Solving Networks: An Analysis of a Critical Incident

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Abstract. This study explores how the Fire and Rescue Service can better prepare for solving complex problems in emergencies by using the concept of problems and problem-solving networks. Primary and secondary data from an extensive fire incident were analysed, including semi-structured interviews and incident assessment reports. Complex problems that arise during emergencies can be challenging to define, and solutions can be difficult to identify. However, this study demonstrates that breaking down complex problems into sub-problems can facilitate the identification of what kind of problem-solving network is needed to be able to solve problems in emergencies. Overall, this study contributes to a deeper understanding of the rationale behind problem-solving network in emergency situations and highlights the importance of relationships in problem-solving network to address complex problems during emergencies.

Keywords: Problem-solving network, Complex problem, Complexity framework, Sub-problems, Problem space, Fire and rescue service

1. Introduction

Emergency situations are often complex and dynamic events that require quick and effective responses to mitigate potential harm to individuals and societies. While many definitions of emergency exist (see e.g. [1–5]) in this paper we define emergency as situations characterised by a high level of uncertainty, unpredictabil-

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ity, and ambiguity. Under such conditions societal response challenges the ability of the Fire and Rescue Services (FRS), and other stakeholders, to solve the myriad of problems that can occur, e.g., fires, explosions, vehicle accidents, shootings. Problems that arise in emergencies often center around complex, or wicked, problems, i.e. those that are ambiguous, open-ended and, in some way, require the flexible adaptation of existing routines as part of their response [6, 7]. These problems are difficult to define, and solutions can be hard to identify [8, 9].

Solving complex problems requires a diversity of perspectives, skills, and knowledge and, therefore, a need for different emergency actors to come together and work towards a common goal [10–12]. This collaboration between emergency actors can be seen as taking place through networks, which can be helpful to quickly identify and access resources, share information, and coordinate efforts [13–19]. A network of inter-organisational relationships with the primary purpose of solving problems in a coordinated fashion can be defined as a Problem-Solving Network (PSN) [20]. Although previous studies have mentioned PSN, their usefulness in emergencies has only been briefly touched upon, as was confirmed by a search in the database Scopus. General research on emergency management networks describes a lack of knowledge of what the driving forces are behind network formation and development [15]. Therefore, studying the rationale behind the network formation and development can be important to fully understand the importance of PSN in emergencies and what drives the networks to form.

In this paper, the aim is to explore how problems and sub-problems can be used as a means to understand the rationale behind PSNs. Although complex problems present challenges in understanding and analysis, Head and Alford [6] posit that it is possible in most cases to break the complex problems down into sub-problems that could be easier to understand. The analysis of an emergency in terms of problems and sub-problems, and their associated PSN fits well with the idea of problem-solving in emergencies [21]. Further, such understanding can help the FRS to better prepare for complex problems by understanding what kind of sub-problems could be encountered and which network could or should be mobilised to solve those problems. In other words, we maintain that it is possible for the FRS to improve their ability to solve problems during incident response, by analysing and understanding how PSN are formed during specific events and learning from such analysis. To this end, we have performed a case study of a major explosion in Gothenburg, Sweden in 2021 [22]. The study involved identifying problems and sub-problems encountered during emergency response, along with the PSN formed around these sub-problems. To evaluate the incident and why the PSN was formed we have used a conceptual framework based on complexity theory.

2. Conceptual Framework

Problem-solving in emergencies are dependent on collective efforts where organisations need to work together to solve the problems that appear [10, 11, 21, 23]. Similarly, Moynihan [13] argues that to identify and apply effective problem-solving when faced with complex problems, such as in emergencies, networks of actors may be required. There are many different ways to describe how actors collectively respond to problems in emergencies, e.g. through teamwork [24, 25], inter-team work [26], or social networks [16]. While teamwork is often discussed in terms of how two or more people cooperate, coordinate and communicate towards a common goal, network formation and development is often studied in wider terms drawing on organisational, contextual, inter-organisational or structural factors [15]. Collaborating in networks is a well-known feature in emergency management literature (see e.g. [13, 14, 27]). Milward and Provan [20] denote networks created to facilitate collective problem-solving in emergencies as Problem Solving Networks (PSN), which is at the centre of this paper.

To further understand how networks are formed and developed in emergencies, this paper focuses on networks which arise in direct response to the problems that are identified. They will therefore specifically be identified as PSN to differentiate them from networks which could exist to foster connections without the immediate desire to find solutions to specific problems. Milward and Provan [20] define a PSN as a set of interorganisational relationships that are shaped by an imminent problem that requires immediate attention and response. This paper has adapted this definition by including the interpretation that the purpose of the PSN is to solve a particular problem, which could be extinguishing a fire or rescuing people from a flooded area, and include components and relationships needed to find solutions to the problem at hand without limiting the network to only interorganisational relationships. In other words, we adopt a view that networks are connected to general system theory [28], where networks that solve a particular problem are interpreted as a collection of interconnected nodes that allow for the exchange, transfer, or flow of information, resources, or entities between the nodes. Nodes in this sense is not limited to people or organisations, instead it includes anything that could be a part of solving the problem at hand. Such PSNs could leverage existing professional networks or develop entirely new connections.

To better understand the rationale behind PSN formation and development in emergencies, this paper explores the concepts of problems and sub-problems. In much of the problem-solving literature, there is considerable agreement that a problem means that there is an undesirable current state, a desired future state with no direct, obvious way to move from the given state to the goal state [29–31].

In emergencies, problems often centre around complex problems. Also called wicked [32], ill-defined [33, 34] or unstructured-unbounded [35]. These types of problems are ambiguous, unconstrained and there are no objective solutions to be found. Current states and goal states are difficult to define, and, in fact, whether there is a problem or not is highly subjective [8, 9], and how to reach the goal might not be agreed upon [36]. In addition, these types of problems cannot be separated from the environment, i.e., they are difficult to place boundaries around, and they appear to have an infinite number of solutions, where one often has to make to with a "good enough" solution.

How humans solve problems has been the subject of lively debate and there are many ways to present the diverse area of problem-solving. A related concept to problem-solving is decision-making and, frequently, the different terms are used interchangeably [37–39]. Theories related to decision making are important to understanding problem-solving. For example, the Recognition Primed Decision model [40] or the simplification of cognitive processes through the use of heuristics (see e.g. [41–43]) are used to understand problem-solving in the FRS. However, these theories are used to understand individual processes and actions whereas the focus in this paper is on collective problem-solving within a network context. In this paper, problem-solving is viewed as a search process using actions to reduce or eliminate the difference between the goal state and the undesired current state [30, 44]. This search process can be illustrated through Newell and Simon [30] *problem space*, see Fig. 1. Here, the nodes represent the current state, the goal state, and possible solution steps along the way. There may be several ways to reach the goal state and selecting a suitable strategy is crucial.

During an emergency, at a given moment in time, some problems are known, and some can be envisaged as possible future problems. New problems, foreseen or unforeseen, appear over time. The situation resembles a dynamic system of problems, similar to Ackoff [45] *messes*, i.e., situations consisting of complex systems of problems that are changing and interacting with each other and are difficult to define. These complex systems demonstrate characteristics such as non-linear interactions, openness to the surrounding and internal adaptiveness, and the system as a whole cannot be understood entirely by looking at its parts in isolation [46, 47]. Despite this latter aspect, in emergencies where important values are at stake and there is a need for swift action, it can nevertheless be useful to analyse the present situation by help of the perspective of sub-problems [6]. Here, we acknowledge the risk of losing the holistic understanding of the situation, but we view the breakdown of complex problems into sub-problems as a necessary first step in dealing with a complex emergency situation.

Figure 2 illustrates the perspective of a complex system of problems in emergencies, using Newell and Simon's problem space [30]. The emergency event represents the main problem, which is the reason for the responding actors to be active in the first place. Within the main problem are sub-problems, some of which are

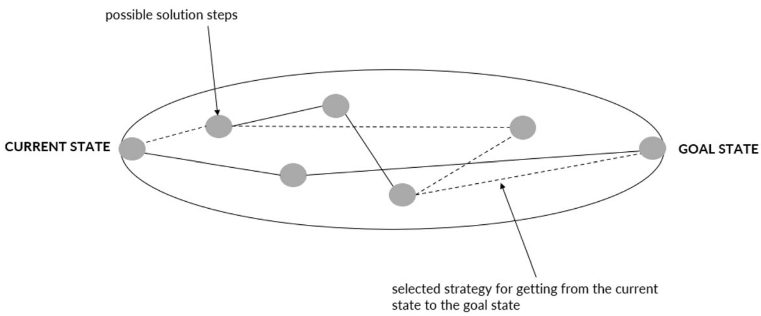

Figure 1. The problem space with the current state, goal state, possible solution steps and the selected strategy. Based on Newell and Simon [30].

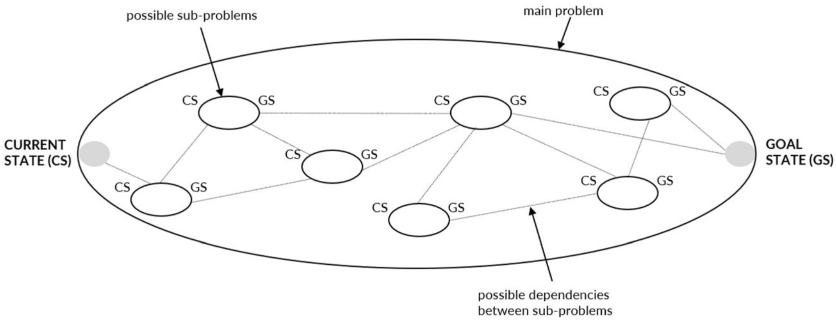

Figure 2. Illustration of the problem space as containing main problem and sub-problems in emergencies (adapted from Newell & Simon [30]).

known, and some are future, potential problems that may appear. Sub-problems and future, potential problems must often be solved before progress can be made toward the main problem's goal state. Distinguishing one solution strategy from another is virtually impossible due to the non-linear interactions between problems and the dynamic properties of the system. This means that it is possible to identify numerous possible sub-problems, and the strategy for moving between them, as well as towards the main goal state, will vary depending on the participants in the process and the situation itself.

Using the concepts of problem space explained above, we investigate the rationale behind PSN formation and development, by applying the Complexity Framework brought forward by Bergström et al. [48]. The framework facilitates an analysis of the complex combination of components needed to address problem-solving in emergency management by systematically exploring sub-problems, components and activities that are needed to find solutions to the problems at hand.

Originally brought forward for studying how emergency response systems achieve direction and coordination, the framework presents how a complex understanding of emergency response management can be generated. The framework is rooted in Cilliers' approach to complexity [47] which implies the need to analyse multiple interpretations of complex systems, make transparent analytical choices, and be modest by making clear that additional interpretations will always be possible. The framework is based on constructing multiple system interpretations where each interpretation is based on analytical choices according to three system aspects: dimension, scope and resolution.

System *dimension* refers to the types of components the system comprises and the types of relationships that bind these components together. Components are, for example, humans, artefacts or functions. Relationships could be, e.g., a flow of information or resources, power, or trust. System *scope* represents the boundary around what components and relationships that are to be included in the interpretation. It usually represents a spatial or functional/organisational delineation, for example, humans present in a certain geographical area, or in a specific organisation. In this study, scope denotes relevant problems that the FRS is trying to solve during a response operation. This will be further described in the data analysis section. System *resolution* concerns the level of detail at which the components of the system are observed, e.g., at single, group or organisational level. A high degree of detail means high system resolution and vice versa.

3. Methodology

Identification of problems, sub-problems and PSN is based on analysis of a single case study [49] of a large-scale incident which occurred in Gothenburg, Sweden in 2021. This section presents the methodology in more detail as a backdrop for the later analysis of both primary and secondary data sources.

3.1. Sample

The primary data consisted of semi-structured interviews with nine interview participants, see Table 1. The focus of the study was on the FRS and how they collaborate in a wider PSN to solve problems, i.e., the sample was chosen to get the FRS perspective. The single non-FRS participant was from the insurance industry, but this participant had extensive experience of the FRS having worked for over 20 years in the FRS.

The sampling procedure started with identifying persons in the FRS who were involved in the incident in a variety of ways based on a combination of the following:

1. Recommendations from the FRS accident investigators,
2. Recommendations from those involved in initial interviews, and
3. Availability to participate in the interviews.

The secondary data used in this study included the incident assessment report created on behalf of the Swedish Civil Contingencies Agency (MSB) [22], the local FRS assessment report [50], an educational video developed by MSB [51], and

Table 1
Summary of Primary and Secondary Data

Primary data	Secondary data
Incident Commander	Incident assessment report by MSB
Team Commander	Local FRS assessment report
Insurance representative (with the specific aim to minimise the cost of the incident)	Educational video developed by MSB about the incident
On-call fire chief 1	Various media articles
On-call fire chief 2	
FRS command centre staff manager	
FRS command centre staff support person 1	
FRS command centre staff support person 2	
On-site staff support person	

various media articles. See Table 1 for a summary of primary and secondary data used to develop the empirical data for analysis.

3.2. Data Collection

An interview guide was created for the semi-structured interviews, see supplementary material file 1. All individuals identified for interviews were contacted, received information about the study and, after informed consent, were given the opportunity to participate in an interview. Two researchers participated in each interview; the first author was present in all interviews while one of the other authors was an observer. The observer was specifically given the opportunity to ask follow-up questions that the primary interviewer may have missed at the end of each interview. All interviews were conducted in a hybrid setting where the person leading the interview was in-person and the observer was virtual. The interviews were all conducted over approximately 1 h. All interviews were transcribed. All interviews were confidential, and handling of personal details was in accordance with Lund University and RISE Research Institutes of Sweden policy for personal data handling.

3.3. Data Analysis

The primary and secondary data collected as part of this study were analysed using the perspective of the problem space, including identification of the main problem and sub-problems, and application of the complexity framework described in Sect. 2. A PSN was defined as a network that arose in direct response to identified problems [20]. Breaking the main problem into sub-problems was viewed as a first step in dealing with this complex system of problems. Therefore, when analysing the rationale behind PSN using the complexity framework, we defined the *scope* in terms of what sub-problems were to be solved during the response operation (main problem). Thereby, the analytic boundary was drawn around what components and relationships were involved in solving those sub-problems (defined as *dimension* in the complexity framework), and the corresponding level of analysis (defined as *resolution* in the complexity framework). Consequently, the data were entered into NVivo 12 and coded according to the sub-problems (*scope*) together with relationships (*dimensions*) and a chosen level of detail (*resolution*).

During this coding process, two of the authors coded a small number of interviews independently and then compared their coding to ensure that these were similar. After this comparison the first author conducted the remaining coding independently while the analysis involved all authors. To gain a deeper understanding of the selected case study, secondary data was identified and included in NVivo for coding in the same way as the interview material. The results of the coding were discussed between the authors until agreement concerning the interpretation of the data was reached. Illuminating quotes are presented to clarify how the empirical data supports the results. Note that all quotes have been translated from Swedish to English by the authors.

4. Case Description

In the early morning of September 28, 2021, an explosion occurred in an apartment building in central Gothenburg, resulting in a fire with extensive smoke spread [22]. Gothenburg is the second largest city in Sweden and their FRS is a local federation which, in 2021, included six municipalities over the region surrounding Gothenburg. The area encompassed around 850 000 residents and had a total area of 3300 square kilometres [52].

In the part of the city where the explosion occurred, most buildings contain private residences (apartments) in the upper floors, with different types of businesses in the lower floors. The explosion occurred in the basement and was so powerful that several fire cell boundaries were compromised, and entrance doors were pushed out by the pressure wave, which allowed the fire smoke to be dispersed throughout almost the whole building. The potential threat to building stability resulting from the explosion was quickly disregarded because the building was deemed capable of withstanding this type of explosions. Additionally, the risk of subsequent explosions was thought minimal, leading the FRS to immediately commence evacuation and firefighting efforts. An illustration of the affected building is given in Fig. 3.

A large number of units from the FRS were called to the scene Upon arrival the FRS observed smoke from windows and balcony doors of various apartments, and about fifty people calling for help. The initial evacuation of approximately 60 apartments was carried out from the courtyard side of the building, during the

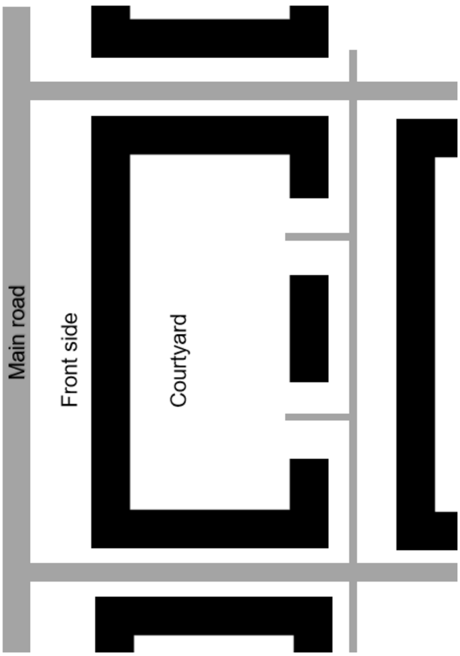

Figure 3. Conceptual illustration of the affected building.

first two hours. In all, three stairwells and associated apartments were affected. One person died due to injuries resulting from the fire and several people had to be taken to hospital for observation. All injured were removed from the scene by ambulance or bus. Residents who were evacuated but not injured, were referred to the nearby church where additional practical help was available, e.g. insurance company contacts, social support and sustenance [22].

The smoke dispersing in the building lead to the initial assessment that multiple fires had broken out and fire identification and firefighting was carried out during the first two hours on both sides of the building, but after the initial evacuation was completed, these activities were intensified at the front side of the building. Almost four hours into the incident response, the FRS realised that the explosion had compromised the fire cell boundaries, and that smoke was crossing these boundaries causing them to initially overestimate the number of individual fires distributed throughout the building. The seat of the fire could ultimately be localised to the storage room in the basement, although the fire had also spread to an adjacent store on the same floor. In the afternoon, the fire was under control, and approximately 24h hours after the explosion, the rescue operation was ended [22]. The approximate timeline of the event is shown in Fig. 4, focusing on the first hours of the incident. Apart from evacuation, identification of the fire and fighting the fire, other problems of a more indirect nature included, e.g. traffic congestion due to the building's central location in the city and anxiety among the public, resulting in an inflow of media requests to the FRS [22].

5. Results and Analysis

To understand the rationale behind PSN from an FRS perspective, the conceptual framework described above, including the concept of problem space and the complexity framework, was applied to the case. Relevant sub-problems were identified for analysis (see Sect. 5.1). Thereafter, the resulting PSN were developed for each selected sub-problem.

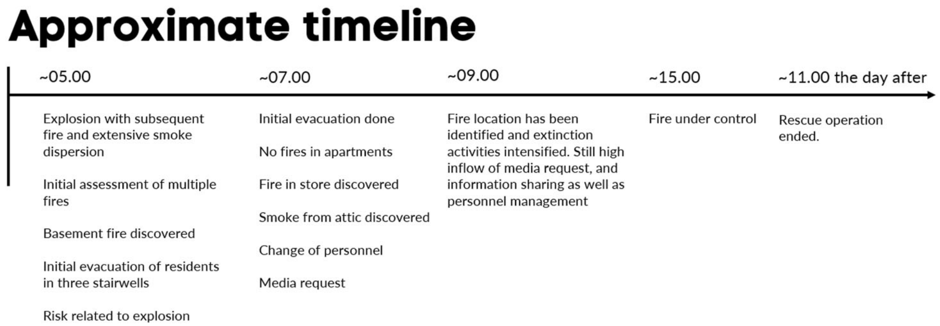

Figure 4. Approximate timeline of event from start of the incident at approximately 5 am day 1 to end of operations at approximately 11 am day 2. The start and close are from the FRS perspective.

5.1. Sub-Problems Used to Analyse PSN

Upon arrival, the FRS identified the current state of the main problem as a burning building with residents in danger, and the goal state as having extinguished the fire and ensured the safety of the residents [22].

Beyond the main problem, the data revealed a complex system of problems that could be further defined through different sub-problems. Respondents described the situation as complex due to the building construction and location in the central city. They further described the situation as chaotic and dramatic due to the large number of residents in need of evacuation and expressed that this incident was different from other incidents that they had encountered due to its chaotic nature and complexity. Due to the extensive resource demand, the respondents described problems of handling the personnel management both on site and in terms of being prepared for other incidents. The chaotic situation also created problems in understanding the situation, both on site and in the command centre. Handling documentation was also described as a problem, along with concerns regarding building stability, informing other actors and taking care of residents after the evacuation. These aspects were described by several respondents as well as in incident reports [22, 50]. The main problem and examples of sub-problems from the FRS perspective is illustrated in Fig. 5 using the concept of problem space previously presented. Potential dependencies between the difference sub-problems have not been investigated in this paper.

Despite the complexity of the situation, data indicated that the focus of the FRS was initially on the evacuation of residents and locating the seat of the fire. Therefore, these two sub-problems were chosen for further analysis in terms of which PSN were formed to solve these problems. Connected to the complexity framework, these sub-problems make up the scope of the two analytic interpretations. These scopes, together with relevant dimension and resolution (see Sect. 5.2 and 5.3), are summarised in Table 2.

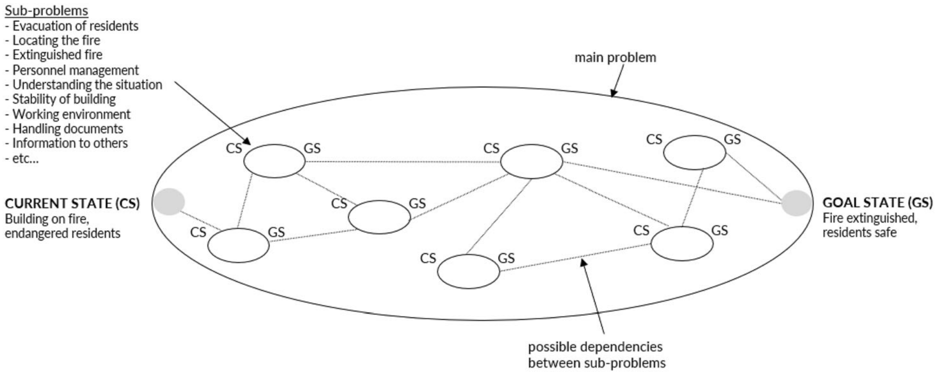

Figure 5. The main problem and example of sub-problems as revealed in the data.

Table 2
The Two Sub-Problems that were Analysed Using Scope, Dimension and Resolution According to the Complexity Framework

Scope	Dimension	Resolution
Initial evacuation of residents	Humans connected by relationships of different support and coordination	Group level
Locating the fire	Artefacts and humans connected by relationships of information flow	Single and group level

5.2. The PSN for Initial Evacuation of Residents

The FRS prioritised the initial evacuation of approximately 60 apartments across three stairwells during the first two hours of the incident. All injured residents were taken from the scene by ambulance or bus, while uninjured residents were directed to a nearby church where their needs were addressed [22]. The PSN which formed to deal with the initial evacuation is illustrated in Fig. 6. Applying the complexity framework, this PSN consists of humans connected by relationships of coordination and different kinds of support (dimension). The resolution is on group level to illustrate that actions from the FRS, police, ambulance, and residents were executed in teams.

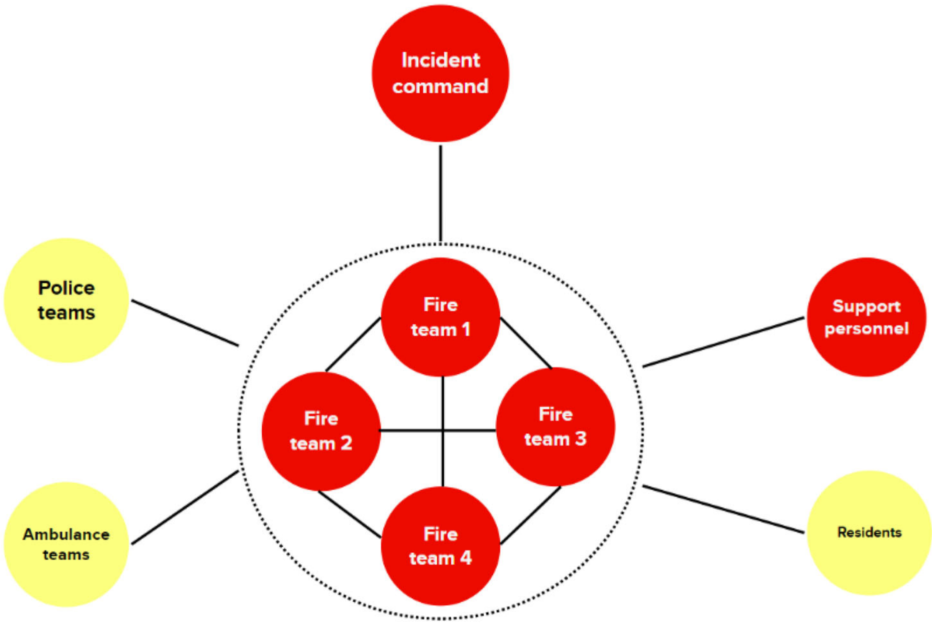

Figure 6. SN for the initial evacuation of residents. Red colour symbolizes the groups from FRS.

The evacuation activities were mainly performed by four fire teams, as shown in the middle of Fig. 6. The relationship between these fire teams concerns coordination of activities. In terms of relationships of support, the Incident Command relieved the fire teams by undertaking tasks of a more comprehensive nature, such as overall organisation and information to other actors [22]. At the same time, however, one respondent from a fire team mentioned that "*[The Incident Command] became very absent in relation to what we are used to [in this type of incident]. Therefore, there was some form of self-organisation at the scene*." Thus, in a sense, the four fire teams acted as one unit, which is why they are depicted with a dashed circle surrounding them.

The relationship of support between the fire teams and the other groups is demonstrated by the ambulance teams taking care of first aid and transportation of injured residents to local hospitals; police teams registering and redirecting residents after evacuation, provided they did not need medical assistance. These types of support allowed the fire teams to focus on searching the apartments rather than taking care of residents after evacuation. This means that the skill sets of the various organisations could be applied to solving problems for their particular skill sets. The fire teams were further supported by support personnel from FRS responsible for logistical matters such as equipment and water [22]. In addition to professional first responders, especially in the start-up phase, two residents offered support by providing their knowledge of the building, including familiarity with the building layout and keys to unlock gates blocking the passage to the building entrance. One of these residents (an off-duty firefighter) also spoke to residents on balconies to prevent them from jumping [53].

The FRS and the other first responders (police and ambulance) encountered a, for them, clear and known problem (apartment fires are common incidents). In some respect, the FRS fell into habitual patterns [22] as exemplified by one respondent: "*… what experience do we have? So, references around past events are a big part of my thinking*". The fact that the residents were standing on their balconies surrounded by smoke made it clear to the FRS that the most urgent problem was evacuation, and it was also clear which resources were needed to solve this problem. As one respondent stated "*It was quite obvious. It's so clear that life-saving is our priority*". Similarly, one respondent identified the most important supporting partners by stating "*I want the police's support here with parts of evacuation and registration of it. And ambulance is very important here…[taking care of injured residents]*". Previous experiences between the FRS, police and ambulance teams enabled the team members to comprehend each other's roles and responsibilities, facilitating the formation of the PSN. This is also described by one respondent as a capability of the PSN members to identify the right context for each actor in a particular moment.

On the other hand, while evacuation is something the FRS train for and are experienced with, the situation was nevertheless perceived as different from what they typically deal with, as exemplified by one of the respondents "*In this case, the conditions for self-evacuation were eliminated and the situation was overwhelming for both the residents and for us at the same time*". Therefore, the outcome was a shift towards a PSN with self-organisation among the fire teams, as opposed to the traditional hierarchical command structure with the Incident Command at the top. One team member experienced that they had to establish a more comprehensive level of communication between themselves compared to in other incidents. In other words, they needed to work as a team of teams rather than as individual teams. This resulted in fire team members experiencing a PSN that was larger than usual and required more collaboration on the part of team leaders. The respondent described that the team leaders needed to take control of on-site activities without waiting for instructions from the Incident Commander. It was also mentioned that this self-organisation between the fire teams was a result of previous training with the police. One firefighter involved in the incident, who was not interviewed in this study, expressed this in an educational video that was developed after the fire [51]: "*... education has given us the ability to work independently, you understand that you need to make many decisions yourself [and not wait for instructions from a higher Incident Commander]*".

Despite the unique scale of the incident, as described both in primary and secondary data, it could be noted that the Incident Command had confidence in the fire teams' abilities to autonomously manage the on-site operations and that detailed management was neither necessary nor desirable. This assessment is reinforced by another respondent who noted that "*In this context, if there had been detailed management, top management, central management, then it would have been very unfortunate. Here, it is important to have control over the right things further up"*. The MSB incident report [22] established that there was an insufficient number of firefighters involved in the initial evacuation. Despite the Fire Chief's communication to the on-site Incident Commander that additional resources were available to assist the teams, it was not perceived that additional resources were needed, leading to a shared perception among the fire teams on-site in the courtyard that no further assistance could be expected. Therefore, the PSN was not developed further even if there was a need for it.

5.3. PSN for Locating the Fire

Locating the seat of the fire is a crucial prerequisite for effective suppression by the FRS. In this case, the fire was caused by an explosion in the basement and during the whole incident the fire was mainly contained within the basement and an adjacent store. However, the process of locating the fire was problematic due to two reasons, leading to a delay of almost four hours before the FRS could understand where the fire was and how it was developing. Firstly, FRS needed to prioritise evacuation of residents in the initial stages of the response and could not focus on locating the fire. Secondly, the explosion that caused the fire breached multiple fire cell boundaries which resulted in the dispersion of smoke throughout almost the entire building. This ultimately lead to the perception of multiple fires and, therefore, the FRS searched for several fires in different locations in the building [22]. Figure 7 present a visual representation of the proposed PSN that emerged to solve the problem of locating the fire. This PSN consists of both artefacts, i.e., floorplans and smoke emerging from the building, and humans, i.e., fire teams, residents, representatives from businesses and the building owner as com-

Figure 7. PSN for locating the fire. Red colour symbolizes components connected to the FRS.

ponents, connected by relationships of information flow. The resolution is both at single and group level as the actions needed to solve the problem involve both single components and groups of components.

Locating the fire was centred around the Incident Command which was responsible for the overall situation understanding and for coordinating the FRS overall response [22]. The figure indicates two important processes where the Incident Command needed to create a flow of information between different components (both artefacts and humans) in order to solve the problem of locating the fire. The two processes were to locate the fire by dispatching fire teams to report on potential fire locations and contacting different actors to gather information about the building [22].

Finding information about the building is one process which is shown in the upper part of Fig. 7. This included different components e.g., the FRS command centre, with help from the municipality, provided information about the building layout by finding technical drawings. The property owner, found through the insurance representative, was able to provide further insights regarding the building layout. Moreover, since the building had undergone renovation, it was imperative to contact the relevant parties involved in the renovation process for input on changes relative to the technical drawings [22].

The lower part in Fig. 7 shows the other process, where the information flow included evaluating each presumed location of the fire within the building. First, smoke was observed emanating from multiple apartments in the courtyard side of the building. Although the primary focus for the fire teams was on initial evacuation, they also attempted to locate the source of the fire in the apartments. The dashed line in Fig. 7 illustrates the lack of information between Incident Command on the front side and the fire teams in the courtyard as exemplified by one respondent "*We had no idea there was a fire on the front side…We wondered why our extinction efforts didn't have expected effect…It was the lack of this information [that it was a fire in the basement] that would have been of value to us.*"

Early in the incident, a crackling sound was identified from the basement by a person walking by (named *individual* in the figure), and a fire team was sent to evaluate the sound. The fire team found a fire in the basement but was unable to extinguish it. Later, a person in the Incident Command observed smoke from a store located next to the basement. Subsequently, a fire team was dispatched to the location, whereupon they successfully located that the fire in the basement had spread to this location. After a couple of hours into the incident, the Incident Commander discovered smoke from the roof which prompted the FRS to prepare for a possible attic fire, but this risk was soon dismissed due to effective communication between the UAV (Unmanned Aerial Vehicle), fire teams and Incident Command [22].

The PSN developed to locate the assumed fires was formed because of the need to obtain a better understanding of the unusual smoke dispersion and the complicated building layout. Although the incident was atypical and did not conform to previously encountered scenarios [22], the Incident Command handled the incident as usual and predicted that where there is smoke, there should be a fire. Two respondents sum this up well: "*it seemed that there were several apartment fires going on together with maybe some type of fire in the basement so that you are very focused on finding these apartment fires at the beginning then. But then after a while you realise that you are inside these apartments and there is no fire but just smoke from somewhere else…*" and, "*the whole house was leaking smoke in a way that it normally shouldn't*". The complicated building layout is exemplified by the following quote: "*It's a tricky building… If it had been a normal Swedish apartment building with three staircases and four floors, that we could have run around with ease, then we would have understood the incident almost immediately*".

This PSN indicates that artifacts can be integral components and can have an impact on the problem-solving process. It seems especially important to obtain an understanding of the building through visual observations, which include on-site inspections and the examination of the building layout and UAV images. Furthermore, the visual dispersion of smoke played a critical role in shaping the network, as shown by the network's formation.

The rationale behind this PSN could be a case of how the FRS try to solve problems by focusing on different sub-problems in both time and space. One respondent describes this way of working through: "*I fly with a drone in my head, I zoom in to the firefighter to think about whether they have the right conditions at the sharp end, then I zoom back and zoom in on Incident Command if they have the capacity, then I zoom out further to see which other actors we have. Then I jump* *forward in time and think about what it looks like if we continue with the same tactics and what it looks like if we were to do nothing*".

6. Discussion

This section discusses how the conceptual framework can be used to understand the rationale behind PSN and how the use of evaluating FRS practice from the perspective of problems and PSN better can help FRS to prepare for solving complex problems in emergencies.

6.1. Using the Concept of Problem Space to Understand the Rationale Behind PSN

The purpose of a PSN is to solve a particular problem. In this paper, we have shown that the FRS develop PSN by breaking down complex problems into manageable sub-problems. In these sub-problems, components and relationships within the PSN can be found more easily. Dividing complex problems into sub-problems is a way to match the situation to previous experience and to more easily identify which actions to take. Actions in this context can be interpreted as the FRS searching for which resources (or components in the network) are needed to solve the problem. Our results indicate that the matching with previous experience [54] will affect the formation and development of PSN, e.g. in the context of locating the fire where the layout of the building and the dispersion of smoke presented a challenge. The Incident Command created a PSN by dividing the problem into several known sub-problem, finding resources that could assist in understanding the building layout and sending resources to investigate each location emitting smoke. This is consistent with previous studies where it is argued that it is possible to divide complex problems into more manageable sub-problems [6] and manage the sub-problems through sub-networks that operate within the larger response network [13, 16, 55]. Even though the initial interpretation of the fire location was incorrect, the use of sub-problems allowed the ultimate outcome of the fire location.

6.2. The Rationale for PSN Formation and Development Exists in Relationships Between Components

The results indicate that the rationale behind the PSN could not be found in the main problem itself, nor the sub-problems per se, but rather in the relationships which contribute to the process of using actions to reduce or eliminate the difference between the current state and goal state. For instance, in the context of the initial evacuation, a clear problem for those directly involved, and the corresponding PSN, was developed based on previous experience. The fire team knew which support they needed and the PSN was formed around the relationships associated with this support. Similarly, the need for coordinated actions between the fire team and the lack of support from the Incident Command shaped the PSN, with the relationship of coordination between the fire teams and surrounding support functions at the heart of the PSN formation. In the context of locating the fire, the incident command function needed different types of information to understand the fire behaviour within the building. This in turn led to the creation of the PSN for the purpose of gathering information, thereby establishing relationships of information flows between different components. An understanding of network relationships can be beneficial to FRS organisations, as it enables them to identify the key actors to approach for information, personnel support, and collaboration on tasks [15].

6.3. The Practical Contributions of this Study

The main practical contribution of the present study is the application of the conceptual framework in the context of learning from incidents.

When it comes to learning from incidents, Frykmer [23] has noted that emergency evaluations often lead to conclusions that are too broad or general to be readily operationalised. Conversely, by applying the conceptual framework in this study and zooming in on different sub-problems in an incident, organisations can identify important components and types of relationships needed to solve the problems and use this as an input to their learning process. The learning outcome from this incident can be summarized in four main lessons learned:

1. *Breaking down a complex problem into more manageable sub-problems makes the problem clear and easier to identify which resources are needed to solve the problem in hand.* A downside of this approach is potentially the risk of losing the overall holistic understanding of the situation, as illustrated by the initial inability of the FRS to locate the fire. The perception of multiple fires was a result of incorrectly decomposing the main problem into (incorrect) sub-problems. This identifies the value of experienced FRS personnel with the ability to quickly reanalyse and redraft their understanding of a given situation.
2. *Informal contacts are important to be able to solve problems at the scene of an accident*. This is exemplified by the support provided by the local resident with firefighting experience and local knowledge of the building and the building owner providing timely structural drawings of the building. Not all buildings have a resident firefighter but building owners can provide detailed building specific information on short notice. Establishing contacts between the FRS and such stakeholders provides significant support as part of a PSN.
3. *Comprehension of different roles and responsibilities facilitates rapid problem-solving*. This is illustrated in the initial evacuation where established routines and contacts between the FRS, police and ambulance personnel facilitated rapid deployment of the PSN and effective evacuation of all residents. This emphasizes the importance of continuous networking and common professional terminology.
4. *Problem solving is not only affected by the people and organisations involved in the incident, but artifacts are also an integral component of the PSN.*

5. This is illustrated in the case of locating the fire where artifacts such as building drawings affected how the problems was ultimately identified and solved. This emphasizes the need to train FRS to include such artifacts in their PSN.

By identifying relationships and components needed to solve problems, the FRS could plan and exercise for important components for problem-solving during emergencies [13]. Using the relevant sub-problems to determine related parameters based on the chosen scope, dimension and resolution [48] can improve the learning potential in an exercise [56]. This approach could also assist the FRS in managing relationships as vital resources, and better comprehending the efficacy of different relationships in addressing emergency challenges [15].

6.4. The Theoretical Contributions of this Study

This study contains several theoretical contributions. First, we have addressed the call for more knowledge of what lies in the relationships within a network (as presented in Hu, Yeo [15]). We see the relationships within a PSN as tools for reducing or eliminating the difference between the current state and goal state [30, 44]. For example, this study has illustrated that the relationships can consist of different types of support, information flow and coordination, that are used to solve the specific problems.

Second, we have contributed to the literature on PSN, as exemplified with Milward and Provan [20]. We argue that it is not only inter-organisational relationships that could explain the rationale behind PSN (as in the current definition by Milward and Provan [20]) instead we should include all components and relationships that affect the process of finding a solution to the sub-problem. To obtain a better understanding of the purpose of a PSN in emergencies, we suggest that the definition of a PSN is expanded to include not only organisations and humans within organisations, but also different artifacts relevant for reducing the difference between the current state and the goal state.

Third, the study contributes to developing the complexity framework by Bergström et al. [48] We believe that the framework can be expanded to incorporate multiple levels of resolution within the same scope, such as components on single and group level. For example, the resolution needed for analysing the PSN in the case of locating the fire contained system components at both single and group level to ensure that interactions between the Incident Command and various components could be captured. The study has also introduced an additional view on scope that can be applied in the framework; that of problems and sub-problems.

6.5. Reflecting on the Research Quality

The perception of a given situation or circumstance can vary widely between individuals due to their unique experiences, biases or role in a specific emergency situation. This implies that what one individual considers to be a problem, another may not [8, 9]. Therefore, the problems identified in this study would most likely have been impacted if more or other respondents had been interviewed.

Moreover, it should be noted that the PSN depicted in this study constitutes a condensed representation. The dynamic nature of a PSN implies that its configuration is in a constant state of change, and a particular representation of the PSN is only applicable within specific temporal and spatial limitations [48], which is a limitation in our study.

In our work, we used two different interpretations of sub-problems. We acknowledge that there will always be additional interpretations. We however maintain that these interpretations captured the most important sub-problems perceived by the respondents and were thus the main problems to cover.

Last, our findings are based on a single case. While the findings may not be directly generalisable, they have contributed valuable insight into how the conceptual framework can be used to gain a more comprehensive understanding of FRS practices through problems and problem-solving networks.

6.6. Further Research

Collaboration in networks has been widely investigated by numerous researchers (e.g., [13–18]. In this paper, we have taken a first step of going beyond collaboration relationships in networks. Our study can be seen as a first step towards developing a better understanding of what network relationships actually mean in problem solving networks. This is relevant for other kinds of network research as previously stated by Hu et al. [15]. Further research could focus on the deeper understanding of the constituents of the relationships, to gain a more profound understanding of the rationale behind the PSN.

In this paper, we have seen how PSN are formed by both formal and informal relationships between the components. Examples are formal relationships between the FRS and other first responders and informal relationships between the fire teams and the off-duty firefighter in the case of initial evacuation. Further research could be conducted to examine whether PSN exhibit formal or informal characteristics. Such research would serve to evaluate the significance of formal organisational structures or prior experience in shaping effective incident management practices.

Finally, investigating the dynamic nature of PSN can provide important insight into how these networks develop over time. Such insight can, for example, be useful for understanding which components and relationships might be valuable at what time during an emergency, to further improve the solving of complex problems in this context.

7. Conclusions

This study has explored the rationale behind problem-solving networks (PSN) in emergency management and how these networks are developed in relation to complex problems that arise in an emergency. It has focused on the FRS and their role in a PSN relative to other actors. The findings indicate that the FRS practice could be understood as breaking down complex problems into manageable sub-problems, which facilitate the identification of components and relationships needed within the PSN. Components includes both people, organisations and artifacts and both formal and informal relationships is important to be able to solve problems at the scene of an accident. Accordingly, the rationale behind PSN in emergencies lies in the relationships that contribute to solve the sub-problems. The conceptual framework used in this paper can assist the FRS in effectively preparing for future complex problems in emergencies by identifying the essential components and relationships required in the PSN to transition from the current state to the goal state of the present complex system of problems.

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Authors contributions

All authors contributed to the study conception and design. LV was responsible for the data collection and coding of the data. TF was responsible for the conceptual framework. The analysis was performed by LV, TF, MM and KE. LV wrote the first draft and all authors contributed to the development of the final manuscript for submission.

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Declarations

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Interview guide

The interview guide that was created for the semi-structured interviews is presented below. Note that the questions have been translated from Swedish to English by the authors.

1. Could you describe the response to the explosion in Gothenburg in 2021

    a. In what way were you involved in the incident?
    b. What needs could you identify in the accident?
    c. How did you identify the needs?

    i. What did you need to understand what had happened and what was about to happen?

    d. How did you identify what actions were needed to meet the identified needs?
    e. Are there any aids that were most important to you in dealing with this accident? What would happen if you didn't have access to these?

2. How has your organization prepared for this type of event? For example. emergency plans/instructions/practices/resources/materials etc.?
3. With the experiences from the accident that you have today, would you have done anything differently? Would you have prepared differently?

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