Dynamic Planning of Fire and Rescue Services

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ABSTRACT

We discuss decision support tools used for more efficient planning of fire and rescue services. The methodology considers small and flexible units and includes dynamic utilization of the existing resources. We develop a quantitative measure for preparedness and use it as a basis for decision support. By constantly accounting for the current situation and using intelligent strategies to locate and allocate resources that support good preparedness, response times can be shortened. The tools will be tested using an experimental setup that includes human-in-the-loop simulations, and the results will compare situations that occur when the decision makers have and do not have access to the developed tools.

Keywords

Dynamic planning, emergency response, decision support tools, dispatch, preparedness

INTRODUCTION

Swedish fire and rescue services have traditionally been characterized by relatively static planning and resource management. In general, emergency resources are strategically located in populated areas and in relation to the risk factors. The firefighters normally wait at the station until they receive an alarm if they are not currently responding to an emergency. There are several problems with this planning strategy:

- The need for assistance varies during the day, which makes it unlikely that resources are optimally located at all times.
- The resources are not always present at the station.
- If a station's resources are occupied elsewhere, the preparedness will significantly deteriorate in the area around the station.

Recently, a new way of planning fire and rescue services has been adopted in Sweden. The new approach divides the firefighters into smaller groups. It is then possible to assign different types of tasks to these smaller groups. For example, some can perform different preventive tasks while others are strategically placed to maintain good preparedness levels. When an accident occurs, the resources with the shortest response times are dispatched. If a small unit is dispatched, it might be necessary to dispatch additional units to achieve full response. This approach is an example of dynamic planning.

Both internationally and in Sweden there have been several scientific studies on how to plan fire and rescue services. These studies have examined the amount of resources needed in a given area to meet the expected demand (e.g., Kolesar and Blum, 1973). The optimal location of fire stations has been studied by Hogg (1968) and Batta and Mannur (1990) among others. Swersey (1982) developed a decision rule for how many resources to send to a specific incident. Ignall, Carter and Rider (1982) and Andersson and Värbrand (2007) have investigated which resources should respond to an incident. Another relevant issue is how to dynamically locate resources when the preparedness is compromised somewhere in an area of responsibility (Kolesar and Walker, 1973; Andersson and Värbrand, 2007).

Most of the research on the planning of fire and rescue services was conducted during the 1970s. A deficiency in most of these older decision models is that they used significant simplifications, especially regarding response capabilities. Usually the models focus on only one type of resource, e.g., one fire engine. When multiple vehicles are considered, they are all of the same type (Batta and Mannur, 1990). Planning that accounts for different types of resources, such as locations of base vehicles and ladder vehicles, are considered (e.g., Schilling, Elzinga, Cohon, Church and ReVelle, 1979); however, each resource's special capabilities are not taken into account as the goal is simply to maximize the coverage. Kolesar and Walker (1973) assume that resources are either at the stations or unavailable, i.e., they do not consider that resources may be available at other locations.

Andersson and Värbrand (2007) developed decision support tools for dynamic planning of ambulances, and their concept may also be applied to fire and rescue services. The present work draws on this previous work to develop and support dynamic planning of fire and rescue services. Special attention is placed on modeling the resource requirements for different types of accidents and modeling the preparedness; this is lacking in previous research.

PROBLEM STATEMENT

The response time is one of the most important factors for survivability in a serious incident. It is therefore essential to ensure that resources arrive quickly in an accident site. It is also important to ensure that the right type of resources (vehicles, equipment) and adequate staffing arrive at the incident. Thus, we consider multiple resources in this study. The resources' specific qualities are also considered to best reflect real-world situations and to meet the demand of each specific incident. For example, a fire accident in a high-rise building may require one base vehicle, one ladder vehicle, one foreman, and five firefighters, one of which must be able to drive the ladder vehicle.

The purpose of this work is to develop tools that can support dynamic planning of fire and rescue services. An example of a dynamic decision may be the allocation of resources to locations near where the preparedness is poor. The preparedness may have deteriorated if an incident has drawn a large number of resources away from an area. With dynamic planning, available resources from other areas can be moved closer to an area that temporarily lacks resources. The challenge is then to determine which resources to move, and where to place them to maintain good preparedness at all locations.

In general, planning, controlling, and decision making about emergency resources occur in a dynamic environment in which conditions change over time. For instance, firefighters are not always found at the station. They may be involved in different types of exercises or be involved in preventive work. Travel times can also vary depending on different situations and on the time of the day. An interesting question is then which resources that should be dispatched to a specific incident. It should be possible to maintain good preparedness for urgent alarms simultaneously with performing preventive work. Both an efficient response to an accident site as well as continuous preparedness for new incidents must be ensured. Relevant decision support tools are helpful to achieve this.

DECISION SUPPORT TOOLS

Models and methods that support dynamic planning can vary from simple rules to sophisticated optimization models. An example of a rule of thumb would be that a vehicle from station A should be moved to standby point X if station B is emptied of resources. A more advanced tool would be computer-based and would propose which resources should be dispatched to a specific incident. The decisions are based on the urgency of the specific alarm, other urgent and non-urgent missions, and the need to ensure a high level of preparedness. The tools would also recommend how the remaining available resources can contribute to an adequate preparedness level, by suggesting how resources should be relocated.

The word *preparedness* is commonly used in fire and rescue services. Preparedness describes the ability to respond to accidents in the present and in the future. It is not obvious how to calculate the preparedness, define the factors that affect the preparedness, or identify what can be considered good or poor preparedness. Different answers are possible depending on different points of view, experience, and personality traits. If the preparedness could be quantified and measured, it should be possible to determine specific preparedness for handling a certain type of incident, as well as to use the result as a basis for decision making and planning for fire and rescue services.

One of the support tools developed in this work is a preparedness calculator which dynamically calculates the preparedness in different areas. This is necessary to meet the main objective in dynamic planning, continuously maintaining a high level of preparedness. The preparedness calculator provides input to other decision support tools. In this study, preparedness is calculated for traffic and fire accidents, as they account for the majority of serious injuries and loss of life from incidents in Sweden (Norrköpings Brandförsvar, 2008).

To quantitatively determine the preparedness, we define the factors that directly affect the preparedness. These include the demand for resources, response times for the required resources, and the expected number of incidents in the area. The preparedness for handling an accident of type *a* in zone *j* can then be calculated as:

$$P_{aj} = d_{aj} \frac{\sum_{i \epsilon I} r_{ij} t_{ij}}{\sum_{i \epsilon I} r_{ij}} \quad \forall\, i \in I, j \in J, a \in A \qquad (1)$$

where r_{ij} is the number of requested resources from zone *i* that contribute to the preparedness in zone *j*, t_{ij} is the response time from zone *i* to zone *j*, and d_{ai} is the expected number of accidents of type *a* in zone *j*. r_{ij} is set to minimize the resources' response times, i.e., minimize the preparedness P_{aj}. This selection is initially performed heuristically, although an exact method will be investigated in the future. It should be noted that a low value corresponds to good preparedness. It may be argued that good preparedness should be represented by a high value, and indeed it is possible to construct a measure that has this quality, although with the risk of introducing non-linearity. However, since the two main components in (1) – response times and risk factors – both improves the preparedness when decreasing, we also let the preparedness value P_{aj} share that feature.

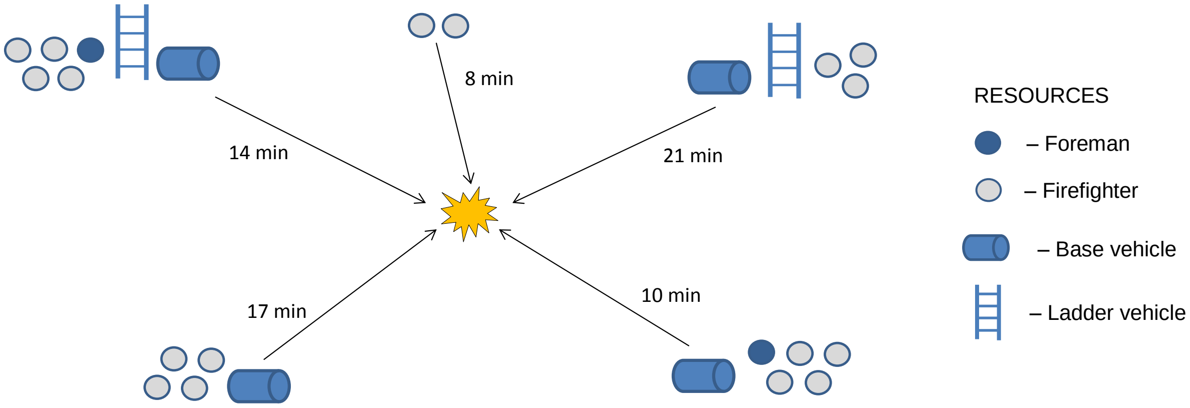

Figure 1. Example of how available resources can respond to an incident and contribute to the preparedness.

To calculate the preparedness for a certain accident of type *a* in zone *j*, the requested resources for the accident type are first considered. The closest available requested resources then contribute to the preparedness in zone *j*. Figure 1 shows an example of an accident for which a number of resources are available. The resources require different response times to reach the accident site. Assume that in this example the accident requires one foreman, seven firefighters, one base vehicle, and one ladder vehicle (this is predefined in the alarm plan for each accident type). The expected number of accidents of this type in this zone is 1.4 accidents per week. Two firefighters can arrive at the accident site within eight minutes; four firefighters, the foreman, and the base vehicle can arrive in ten minutes; and the remaining required firefighter and the ladder vehicle can arrive in 14 minutes. The preparedness for this accident is calculated using (1) as:

$$P_{aj} = 1.4\, \frac{(2*8+6*10+2*14)}{10} = \; 14.56$$

The result itself does not determine if the preparedness is good or poor, however, a lower value indicates better preparedness. The preparedness value should be validated and compared using a number of different test cases. The next steps in this work are to calculate the preparedness for a number of different scenarios in a test area, and validate the model using professional staff from fire and rescue services.

As mentioned above, the decision support tools should contribute to more efficient dynamic planning and control to maintain a good level of preparedness. The preparedness calculation is therefore very important for the other decision support tools. For the example in Figure 1, the decision support tools could be used to suggest which resources to dispatch to the accident site in order to maintain good preparedness throughout the area of responsibility. In the case of an urgent alarm, the resources with the quickest response time will likely be dispatched to the accident site, i.e., the same as used in the preparedness calculation. If the preparedness elsewhere has deteriorated to an unacceptable level, the decision support tool would suggest how to relocate the remaining resources in order to restore the level of preparedness in the area. If it is a non-urgent request (for example, an education session), the decision support tool will probably make other suggestions on how resources can be dispatched to the site in order to maintain good preparedness. Depending on the situation and type of incident, the resources to be dispatched do not always need to be those that can arrive most quickly at the accident site. In some cases, it may be more important to send a quick first response while additional resources can arrive later.

EXPERIMENTAL METHOD

A number of experiments are planned to compare decision making and resource allocation both with and without use of the developed decision support tools. The experiments will be performed in a simulation environment in which 20 different fire and rescue services in Sweden will perform a series of test scenarios. With the same series of test scenarios, half of the test groups will have access to the decision support tools and half will not. This will enable comparisons of the decision making results, approaches, and planning methods. The results will also enable a quantitative and qualitative analysis and comparisons of the groups' performed activities, response times, resource consumptions, and preparedness levels.

RESULTS

During the first phase of the project, a number of fire and rescue services in Sweden have been interviewed to investigate their current use of dynamic planning and their need for decision support tools. The interviews show that there is a large difference in the fire and rescue services regarding planning and management of resources. Some services use dynamic planning extensively while others rarely use it. These differences originate from variations in available resources, areas of responsibility, and work procedures.

It is expected that the resulting decision support tools will facilitate the use of dynamic planning and thereby contribute to a more efficient fire and rescue service. The series of experiments will provide valuable insight into how fire and rescue services can work with dynamic planning and the effect this may have on operations.

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