Risk Based Decision Making on Accident Scenes

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Abstract
Rescue operations on scene are usually based on rigid management systems. Such systems are traditionally emergency plans, written procedures and predefined arrangements and measures for the on scene activities. The practices are based on a military strategy, in which the management is authoritative and centralised around the on scene commander. The term commander pinpoints this view. This paper discusses established approaches to on scene management as it is presented in accident investigations, literature and personal experiences from the Rogaland region in Norway. We then, theoretically, apply the concept of risk-based decision making as an approach for the management of rescue operations, and we discuss implications of a strategy based on functional reasoning on scene. There are different challenges upon a shift towards a risk-based approach for on scene management. The paper discusses premises to be considered, if the risk-based approach shall succeed as a powerful management strategy.

Introduction
The TIEMS conference 2002 in Waterloo, Canada, focused on the terrorist attacks on the World Trade Centre (WTC) and Pentagon, September 11th 2001. The documentary film; *The Attack on the World Trade Center Sept 11th 2001*, by J. and G. Naudet (2002) was shown at the conference, and special sessions and key note speeches were given. The first and strongest impression on us was the initial phase of the WTC disaster, in which the fire chief in command was setting up the command post in the lobby of the burning building. In this particular scene, the on-scene commander was studying drawings of the building and the emergency plans, while the troops were standing by. The grins of their faces and their shifty-eyes expressed serious uncertainty of what to come. The stories of the rescue efforts at the World Trade Centre have been and will be analysed by many researchers, for example Smith, (2002), Columbia State University (Homeland Security, 2003) and National Institute of Standards and Technology (Homeland Security, 2003).

The rescuers were not prepared for the WTC-scenario. And, it is practically impossible to prepare for catastrophes like that. How shall we meet extreme unlikely events? Emergency management is a dynamic process, in the sense that the work domain changes for each emergency situation. Each situation is unique and its circumstances are often badly structured and, consequently, the combating actors, especially the first responders, will know only broad general features of the scenario characteristics. Thus, uncertainty is an inherent feature of emerging accidents, and this uncertainty must be dealt with.

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The teams from one rescue operation to another changes, as the commander and team members do (Rasmussen, et al. 1991). The decision problem on scene is dependent on the individual leader's and rescue team's ability to meet emergency situations. This implies that the decision maker needs to know in *which situations* he/she must act, the decision maker must be *familiar with* his/her tasks, the decision maker must be *able to perform* his/her tasks in an appropriate way and be able to *evaluate the consequences* of his/her own commands. However, even though every situation is unique, they can normally become generalised into standard response routines. Roughly, we will claim that about 5 - 10 % of all responses can be characterised as not normal to the responders, involving factors that require deviations from standard procedures.

A successful outcome in a crisis depends on several factors. One important factor is the decision-making in the first minutes, and hours of the crisis (Kowalski and Vaught, 2001; Robert and Lajhta, 2002). The on-scene commander is essential, especially when the crisis is novel, the consequences are unclear, different authorities are involved, many actors struggle on-scene and the media are paying particular attention. The response group that first arrive at the accident location, consists of a limited number of rescue personnel (police, fire brigade or ambulance). In Norway and Sweden normally 2 – 6 persons are involved in the initial phase, in which a low ranked officer carries out the commanding on scene. The nominated commander on scene arrives later, within an hour after the first alert has been received.

In the remainder of this paper we discuss strategic choices made by commanders, and in particular the reasoning behind those choices. A risk-based approach to handle crises at the accident scenes is described, and our aim is to give recommendations and discuss how to approach risk and uncertainty to support decision-making on accident scenes. We claim that a risk-based approach could improve the emergency managers' performances.

Three study approaches

Our study of on-scene commanders, so far, has been three folded. Firstly, three public accident investigation reports, two Norwegian and one Swedish report, has been studied. Secondly, a literature study has been carried out, and thirdly, five on-scene commanders from Rogaland County in Norway have been interviewed, whereof police, fire brigade and first aid all were represented.

The accidents investigations studied are:

- Train collision at Åsta, Norway, January 4th 2000, 19 killed and 30 hospitalised (NOU 2000: 30).
- Train collision and subsequent propane gas leak and fire, which threatened parts of the Lillestrøm town, Norway, April 5th 2000, (NOU 2001: 9).
- Fire in the discotheque in Gothenburg, October 29th 1998, 63 killed and nearly 150 victims received intensive care (Statens Haverikommisjon, 2001).

The same investigation commission wrote the two Norwegian investigation reports. A common observation from the accident investigation reports is the lack of analytical perspective with respect to the rescue operations. The narratives from the alarms has reached the responders to the situations are stabilised are presented as facts. The emergency management performance and the commanders' way of thinking in action are superficially evaluated. Why the rescue operations do not attract the investigators' attention is not clear to us. We need more empirical data to conclude on trends in accident investigation practices. The Gothenburg investigation is a study in-depth on the accident activities, but the on–site management is rather superficially discussed.

In an accident inquiry the starting point is, of course, to reveal the truth about what really occurred and why the accident took place. Lessons are to be learned! However, the limited focus on how the emergency responders performed undermines knowledge on how rescue operations can be improved. Is guilt and blame on rescuers part of the explanation? The status of these workers is, at least in Norway, unique and nearly unassailable. The major issue when the emergency management on–scene is investigated is: *Was there written procedures/plans, and was the work accordingly carried out by the rescue teams?* The investigators, to the extent criticism is raised at all, refer to whether or not procedures are complied with. The functionality of the rescue work, and analytical evaluation of alternative strategies and measures taken, is practically absent in the investigation reports.

The Åsta accident was distant from the nearest hospital, and the fire was intensive when the fire service arrived. Large amounts of diesel were on fire and it was complicated to extinguish, especially since the diesel was underneath debris below the carriage with stuck passengers. The water and foam availability was poor. An alternative water source was a river 600m from the scene. At least eight of the stuck passengers were alive when the fire service began their work. Why did not the commission focus on the important decisions made on scene and the process leading to the choices?

The Lillestrøm accident occurred an hour after midnight at the Lillestrøm station. The fire service was alerted and at an early stage they became aware that the "burning tanks" (propane gas leakage from a crack) had to be cooled with water. The cooling was established rapidly. However, the responders did not have specific knowledge of the hazardous situation and probable consequences. They continued cooling the tanks. Experts were called in for help, but this was time consuming since they had to travel from Tønsberg (approx. 200 km away). The management was afraid of BLEVE[2], a gas explosion or a fireball, which has the shape of a hemispherical burning cloud, which emits heat over a relatively short period of time. About 2000 people were evacuated from the danger zone, estimated at 1000 meters from the tanks. The evacuation was finalised 8 - 10 hours after the collision. Eventually, the situation was stabilised without further damages. The commission's attention was paid to the central command and very little to the on–site commander, and consequently, training and competence improving measures were recommended for rescue personnel. No analysis or assessment related to decisions on the accident scene is presented.

In Gothenburg, a fire broke out at the second floor of a meeting hall applied as a discotheque for teenagers. The first responder group - a fire engine - was exposed to:

- Limited information in advance. The fire captain saw the smoke plume just before arrival and thought it was garbage burning.
- Chaotic situation;
    - Many youths, according to the captain many hundreds were in front of the building. In the aftermath it was ascertained that 380 persons from 19 different countries were inside the building when the fire started
    - People falling/jumping from windows
    - Flames out of at least two windows

The captain ordered more resources from other fire stations. His first command to the crew was: "Now it is time for lifesaving - we have to save lives and avoid violent bystanders and victims" (Hagström and Sundelius, 2001). The fire fighters should concentrate on rescuing victims, and neglect fighting the fire. No further orders were given to the response groups the next minutes. The actions were not coordinated, and each fire fighter acted apparently on their own. Later on, 28 minutes after the alarm, the senior officer arrived, and after 49 minutes the nominated commander on scene showed up. These commanders did not carry out situation recognition, nor did they analyse the situation to optimise the rescue strategies. The Swedish report is detailed with times of alerts, arrival of resources and actions. Critical evaluations of decisions are made in this report, and followed up with some recommendations.

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[2] BLEVE = Boiling Liquid Expanding Vapour Explosion

If we maintain our beliefs that accident investigation is an important tool in societal and organisational learning, more than the situational facts are necessary. The perspective must be somehow analytical, in which all parties are included in the evaluations. The three investigation reports are more concerned about the parties directly involved in the accidents, not about the emergency responders. Evidently, first line actors (the sharp end) become more criticized than second and third line actors (the blunt end), in these investigations (Njå, 2002). To us, in this study, it has not been important whether the on-scene commanders performed well or not. We simply conclude on the lack of analytical approach to the emergency response part of accident investigations.

What about the scientific literature? Rake (2002) gives an overview of different on–scene decision-making models. He concludes that many of the models are abstract, incomplete and lack practical perspectives. In an operational point of view, one of the most interesting model for on-scene commanders, is the Recognition-Primed Decision (RPD)-model (Klein, 1989; 1993). The RPD-model is a process model, where decision-making is a sequence of activities. The process consists of three typical phases; *Situation recognition*, *Serial option evaluation*, and *Mental simulation*. Klein claims that expert decision makers rarely compare different alternatives. Instead they assess the essence of the situation and its demands. Then they select an action, which they know will cope with the urgent situation. Cosgrave (1996) and Dreyfuss and Dreyfuss (1986) support this perspective on the mental reasoning of experts. Dreyfuss and Dreyfuss describe an expert as a person who generally knows what needs to be done based on mature and practised understanding. When things are proceeding normally, experts are not actively solving problems or making decisions, they are intuitively doing what normally works. Whilst most expert performance is ongoing and non-reflective, when time permits and outcomes are crucial, an expert will deliberate before acting. This deliberation does not require calculative problem solving, but rather involves critically reflecting on one's intuition.

Can we then conclude that the intuitive expert on-scene decision maker is the general solution to all our problems? No, a rescue operation is not carried out in a controlled environment. Earlier experience, formal procedures, informal rules, norms and processes affects how the individual commander thinks and performs leadership in emergencies. The world is too complex for single experts. Rasmussen's (1982) behaviour model categorises different types of decisions: *skill based* decisions, *rule based* or standard procedures (if-then) decisions, and *knowledge based* decisions. The latter refers to novel situations, for example crises not prepared for. We were curious about how experienced on-scene decision makers in Rogaland based their decisions, and prepared a separate study. It is emphasised that this study is temporary only, and will be extended.

The study was based on interviews with five on-scene commanders. A case - fire in a combined restaurant and discotheque building in Stavanger - was described to the interviewees. The interviews were open ended and in–depth, focusing on the leaders' way of thinking and making decisions in situations with a high degree of uncertainty. The questions comprised how they prepared before they arrived the scene, how they would combat the scenario until the situation was normalised. The major findings, supported with some quotations, were:

- The commander expects normal situations in which the effort can be generalised. "When coping with a situation that is not normal I use a normal situation as a starting point"
- The commander is neither prepared for catastrophic events, nor for very novel situations. "I do not think of worst cases – does the alarm message indicate fire, I think of it as a fire."
- Risk based evaluations are usually limited to evaluations of responders' safety. "When I am thinking about risk I always think about matters I want to avoid", "When I am thinking about risk I always think of my crews' safety and about the equipment".

- The commander does not apply abstraction in problem solving. "When I climb out of the car, I always look for the leaders of other response groups"
- The decision process is characterised by incremental problem solving effort. "Precautionary planning - is that necessary? We take things as they come." The commanders' focus are; on details, on practical solutions, on here and now situations. They have a narrow time horizon.
- Characteristics of excellent commanding on-scene: He or she has good routines for information gathering and communication, he/she is visible, available, determined and able to make decisions, and he/she is co-operative. "A successful response is when I have used my resources the right way".

The commanders were surprisingly unanimous in their approaches to commanding on-scene. Even though we did only five interviews, the resemblance seems typical. Of course, this could be a local cultural phenomenon in the Rogaland region. However, the interviews confirm that commanders are narrowly focused, in the sense that the first arriving commander concentrate on owns professional tasks and he seldom takes the overall responsibility. The interviews support our experience that the first arriving leader acts as a matter of standard procedures, normal routines and experience, which is regarded suitable in all situations. Regester and Larkin (2001) recommend risk assessment when risk changes, which is typically during a rescue operation on an accident scene. Today, risk is not a prominent term for the on-scene commanders. In order to ensure flexibility of the responders' capabilities, the rigid procedural thinking could be developed to include real-time risk assessment.

Risk and on scene decisions

The term risk is related to future outcomes and related probabilities. Is risk an interesting perspective for on-scene commanders? The answer is not clear. The dominant concept of risk, what we will denote as the *engineer perspective*, is not useful to on-scene commanders. The engineer perspective views risk as an inherent property of the system, in this case the accident scene, and the purpose of a study of the risk is to reveal the true risk/probability. Thus, a sharp distinction is made between the real objective risk and the perceived subjective risk. The focus is on the risk figure, which is an unobservable unknown quantity. We reject this view on risk to support decision-making on-scene. The engineer perspective is described in several textbooks and papers, see for example (Henley and Kumamoto, 1981; Rausand, 1991; Modarres, 1993; Vose, 2000).

An alternative concept of risk focuses on observable quantities. Related to on scene activities, such quantities could be the number of victims trapped in an earthquake, volume of gas from a gas leak, diffusion of an ammonia cloud, location of children caught in a fire scenario, materials exposed to fire, occurrence of structure breakage during fire fighting, time and capacity to carry out rescue operations, the number of injured and killed victims, injury categories and so on. Such quantities are of interest to the on scene commander in the real-time of the emergency. However, these quantities are uncertain, and this uncertainty is expressed by probabilities. In this sense, the risk is purely epistemic, we are uncertain because we lack sufficient knowledge. The on scene commander can apply this concept of risk in his work in order to firstly, *decide what kind of information is needed within specific time frames*, and, secondly, *decide which strategies and measures to be taken in real-time*. We denote this concept of risk as the predictive approach to risk (Aven, 2003). The foundational issues of risk are for example discussed in Apostolakis and Wu (1993), Aven (2003), Hoffman and Kaplan (1999) and Nilsen (2002).

Traditionally, risk analysis could be applied to support emergency preparedness planning. However, the approaches seen in emergency planning varies substantially from focus on detailed solutions to focus on performance of rescue operations, cf. Njå (1998). The latter implies normally that risk analysis is applied to develop situations of hazards and accidents to base the design of the emergency response arrangements. During the risk analysis process the design of the emergency response arrangements, organisation and procedures are developed. This paper does not deal with emergency preparedness planning, but coping with risk and uncertainty on scene prerequisites an understanding of performance.

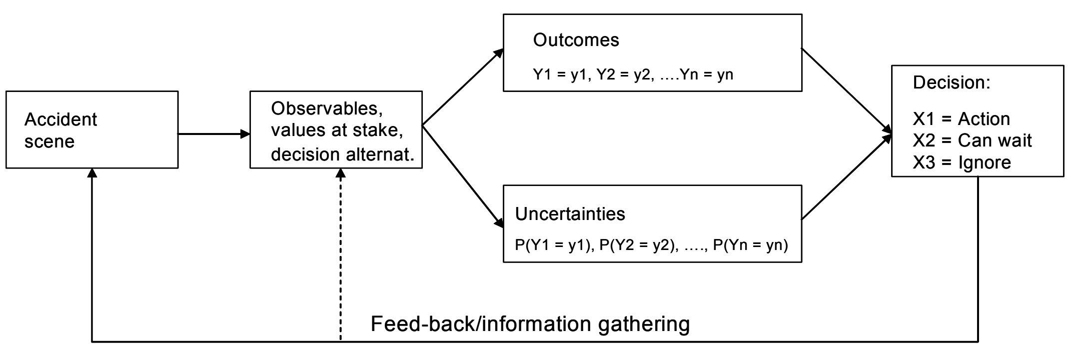
The on scene commander's dilemmas are quite different from planning issues. The decisions are to a great extent dependent on the time factor. Edwards (1962) gives some characteristics of dynamic decision-making. Firstly, *a series of decisions is required to reach the goal*, a successful outcome. Secondly, *the decisions are not independent*. One decision influences later decisions. Thirdly, *the state of the decision problem changes*, both autonomously and as a consequence of the decisions already made. Brehmer (1992) adds a fourth characteristic; *the decision has to be made in real-time*, which means that the decision maker is not free to make decisions when he himself wants to. He/she cannot wait until he/she has gathered all the information, made the analysis and organised the necessary resources.

Decisions on-scene is made upon some information. Sometimes our uncertainty is regarded too large and not acceptable to make a decision. We need more information, but *the decision has to be made in real-time.* The decisions must be made in accordance with the demands of the situation. If it is not possible to postpone the decision, the commander simply makes his decision. Such decisions have of course a greater uncertainty, in the sense that the background knowledge should have been better. We have to make trade–offs quickly based on real-time constraints, in order to respond effectively in real-time.

RBDM - Risk Based Decision Making

Human decision-making might be thought of as a process where individuals construct certain maps to help to clarify their thoughts and subsequent actions. The map summarises the interdependence of variables, or the influence that one variable might have on another. We define the map as a model. In a risk based decision-making context based on the predictive approach, the on-scene commander will follow the steps depicted in figure 1.

Figure 1. Risk Based Decision Making (RBDM) -model



The purpose with RBDM is to establish a way of thinking on scene that is general and independent of the actual situation. RBDM enforces the decision maker to place the focus on the quantities regarded important, and RBDM require that the decision maker (on-scene management team) evaluates uncertainties systematically. Through active use of the RBDM-model, we believe that uncertainties will become reduced, decisions made will improve the on-scene performance, and that fewer abnormal accident situations become unsatisfactorily managed. The key principles of our recommended risk approach are the following:

- The process is ongoing throughout the scenario, from being alerted until the situation is normalised.

- Based on available information, identify the observable quantities involved, including the critical values at stake (lives, environment, and assets). Clarify decision alternatives.
- Predict the outcome of the quantities, in a specified time horizon. What *can* happen?
- Uncertainty related to the observable quantities and the predictions is expressed by probabilities (for example percentages).
- Decision is made amongst the alternatives: (X1) Action is necessary, (X2) Can wait, (X3) Ignore/ Keep under observation.
- Feed-back is ensured, both with respect to efficiency of the decisions made and related to general information gathering efforts. The efficiency could be measured directly on changes to the observable quantities (dotted line).

Let us illustrate the model by the following example. The southwestern part of Norway (Rogaland) consists of a variety of mountains, valleys, moors, woods, fjords, farmland etc. Let us say that the fire alarm is given (a phone call) late in the evening - a bushfire in a specific area. What now? Certainly, standard procedures are followed, engines are equipped and firemen preparing for action and transportation to the scene. What information is available for the management? The information from the alarm central is important, maps of the area as well, weather forecasts and status, and people acquainted with the locality. The first step – which quantities to identify? **Critical values:** Human beings in the vicinity (including responders), protection worthy nature, buildings and other assets in the area. **Observables:** Temperature, wind (speed and direction), fire zone and materials on fire, fire speed and intensity, accessibility to the fire scene, extinguishing equipment, human resources and the topographic. **Decision alternatives:** The commander is on her way to the fire scene, and has got three options: She can command people out to combat the fire at the moment she arrives, she can wait in order to optimise a strategy for extinguishing, or she can ignore the fire – just maintaining surveillance.

What is her knowledge status upon arrival? She knows that the nearest building is 3 km from the fire front, which is also the distance from the fire engines (nearest road). The terrain is near an old forest, important to protect. The forest is located on a lower level than the fire scene. It is dark and the terrain is difficult to access. The temperature is approximately 0° Celsius, and the wind direction is away from the forest and nearest building.

Outcomes: Responders are vulnerable in the darkness with difficult accessibility (falling, trapped in fire, loss of communication, etc.). Other people could be in the area, but there exists no such information. The fire could spread to the wood and later on reach the buildings nearby. **Uncertainties:** She assigns a high probability (70%) that responders would become injured if fire fighting commences immediately. She relies on the weather forecast indicating stable weather conditions through the night, and she assigns a small probability to the forest and building will be caught on fire during the night (less than 5%).

Decision: She decides to carry out a helicopter reconnaissance, and wait with fire extinguishing until the dawn the next day, given that the reconnaissance does not give new and vital information.

The process goes on, and she applies her cognitive maps to evaluate risks. This is the feed-forward strategy. Of course, when her knowledge in some fields is limited, she needs to involve external resources (experts), such as the meteorological expertise. The time factor plays an important role for the cognitive modelling and subsequent decisions. Participation of the involved parties in strategies and decisions is also important, but it does not conflicts the risk-based orientation of the decision-making. In this model we have combined feed-back and feed-forward strategies, in line with the ideas of Orasanu and Connoly (1993) - introduce a commanding strategy on-scene, employing feed-back loops, and Brehmer (1992) - adds feed-forward strategies to deal with the changing situation in real-time.

Discussion

During our studies of emergency management activities, it has become evident to us that emergency response operations are not exposed to external critical evaluations. When things go wrong, only the involved parties will know. Society will only react if there have been clear violations of rules and norms for rescue work. The rescue operations are normally carried out by conscientious rescuers doing their best to optimise the consequences and mitigate losses. However, the performances of the operations rest on standard procedures and experiences from "normal" responses. The on-scene commanders decide what normally works, which is strategies and measures they are familiar with. The degree of innovation amongst emergency responders is scarcely developed.

The internal debrief activities subsequent rescue operations are more concerned with orientation of facts and moral support, than critical evaluations of efforts and decisions made. It can certainly be questioned, whether there exist learning processes on organisational levels within each department, and we will claim that in-between departments experience transfer is nearly absent. The professional rescuers are stuck in a military organisation structure that lacks principles for self-evaluation and improvement.

According to Worm (2000) systematically structuring the information on-scene is a rational way of managing uncertainty. Worm operates with 7 key categories of requirement to the information retrieval; Reliability - Availability - Relevance - Diagnosticity - Complexity - Level of abstraction - Level of aggregation. This information approach is interesting, but to us it is not clear how the approach could be applied on accident scenes.

We are surprised by the dramatic gap between the operational emergency environment and the work of the research environment. The development of different software tools to assist on-scene performance is based on too optimistic premises. We think that future research should be based on actual premises on-scene, and new tools and methodologies should not be developed unless implementation strategies are developed in parallel.

As a first step to an organisational improvement, we have recommended risk-based decision-making. The focus is on observables, and those observables that are important for the response performance. RBDM is simple, and that is important to us. We believe that risk based thinking amongst decision makers on-scene, only can succeed if it is simple to use, and not too far from existing practices. Thus, it is crucial to use the RBDM way of thinking during the normal responses, the responses in which the standard procedures work very well. RBDM must be a part of the normal assessment on the accident scene, minors as well as majors. In the Gotheburg fire and Åsta train accident the nominated on-scene commanders were in action respectively 49 minutes and 46 minutes after the first alert. Thus, it is questionable whether their presence did have effect on the response performances. We will claim that the Åsta and Gothenburg experiences are typical for rescue operations. Regardless of the commander response time is improved, we recommend that RBDM be broadly understood by operational responders.

We cannot blame the emergency management environment for the lack of risk based thinking in their emergency response practices. It is the risk assessment environment that has complicated the risk concept, which excludes all other than the risk assessors to perform evaluations about risk. In this way the risk assessors have made a sharp distinction between the correct objective risk values and the subjective perceived risks, which cannot be relied upon. Thus they place themselves as experts that the society and other markets must employ for advice. This is an infringement supported by the positivistic scientific tradition, which has probably caused more harm than better safety to society.

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Ove Njå, Ph.D, is an Associate Professor at the Stavanger University College. Ove Njå has many years experience from R&D projects from onshore and offshore-related industry. His doctoral thesis is related to safety management and emergency preparedness planning. Njå has led research projects connected to risk and uncertainty that spans from assessing effectiveness of emergency preparedness training to development of an approach for assigning subjective probabilities in risk and vulnerability analyses. At the Stavanger University College he is involved with the safety and resilience management study program, and he is also a Senior Researcher at Rogaland Research.

Eivind L. Rake holds a MSc. in Civil engineering, and he has almost 20 years experience as commanding officer in a fire department. He is fire – chief in Sandnes Fire and rescue service. Rake has led projects connected to risk and vulnerability, which spans from emergency preparedness in municipalities to regional hazardous material responses. At the Stavanger University College he gives lectures in risk and vulnerability analyses and he is currently a PhD fellow carrying out research in the area of emergency preparedness and emergency management on - scene of the rescue operation.

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