A Method for Modeling Human Behavior as a Dynamic Process in the Context of External and Internal Hazards

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Abstract. The execution of a human procedure is a dynamic process which highly interacts with the changing system state over time and also depends on random events (so-called aleatory uncertainties) influencing the system state and the environmental conditions of the plant. For that reason, it is particularly important to model time-dependent interactions and aleatory uncertainties when human actions are required in case of external and internal hazards, which may have different kinds of impacts on the affected plant. The paper presents a method (Crew Module) that allows modeling and simulating a human procedure as a dynamic event sequence which may depend on system states as well as on aleatory uncertainties. Relevant dependencies and interactions are discussed, which may significantly influence the assessment of human reliability and therefore ought to be modeled in more detail. A demonstration example of a procedure for firefighting is used to give an idea in what detail dependencies and interactions can be modeled and analyzed with the proposed method.

Keywords: External and Internal Hazards, Knowledge-Based Human Behavior, Stress, Human Reliability, Probabilistic Dynamics, Aleatory Uncertainties.

1. INTRODUCTION

External and internal hazards such as flooding, earthquake, aircraft crash or fire affecting a complex technical facility like a nuclear power plant (NPP) are associated with various sources of uncertainties. One source of uncertainty concerns the different kinds of impacts a hazard may have on the affected plant. Moreover, some of these impacts may lead to cascading effects which tremendously increase the problems to deal with.

For many of these potential impacts, human actions are required in order to prevent, manage or mitigate harmful consequences arising from those hazards. Hence, in case of hazards human actions have to be regarded as an important part of safety and emergency functions in a NPP. Particularly under accident conditions arising from the unforeseen impacts of hazards or combinations of hazards, situations are likely to occur which are unfamiliar and unexpected to the plant operators. These unfamiliar situations constitute a more or less difficult problem to be resolved by the plant personnel. Finding a solution to the problem heavily depends on the knowledge and experience of the operators as well as on the complexity of the problem. Knowledge-based behavior, which is required in these situations, is a process where novel strategies of actions have to be generated and carried out in order to prevent or at least to mitigate adverse effects on safety.

The highly demanding task of solving more or less complex problems within a restricted time period may increase the stress level of the personnel involved. The increase of the stress level of a person in turn might affect the reliability of human actions. The behavior of stress within a human procedure might depend on different aspects, e.g., the system state, the failure and required time of preceding actions, the time period needed for recognizing a problem and reflection upon a solution strategy. The behavior of the stress level depends on the dynamic behavior of the system as well as on the performance of human actions. Therefore, the development of stress level over time within a human procedure has to be regarded as a dynamic quantity.

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Actually, conducting a human procedure is a dynamic process which highly interacts with the changing system state over time and also depends on random events (so-called aleatory uncertainties) which may influence the system state and the environmental conditions of the plant. For that reason it is important to model human actions as a dynamic process where time-dependent interactions and dependencies from aleatory uncertainties and system states can be taken into account.

In order to model those time-dependent interactions between human actions, system state and random influences advanced probabilistic dynamics methods in human reliability analysis (HRA) are required. A method (the so-called Crew Module) has been developed by GRS which allows modeling and simulating human actions as a dynamic event sequence depending of aleatory uncertainties and system states.

In the following Section 2 relevant dependencies and interactions of human behavior are discussed which ought to be considered in HRA because they may significantly influence the assessment of human reliability. A methodology is proposed which allows considering such dependencies and interactions in an appropriate way. The concept of the method is briefly outlined in Section 3. Section 4 provides a demonstration example of an internal hazard aiming to illustrate how human actions which may depend on aleatory uncertainties and system states can be modeled as a dynamic event sequence.

2. RELEVANT DEPENDENCIES AND INTERACTIONS TO BE CONSIDERED IN HUMAN RELIABILITY ANALYSIS

In the analysis of human actions many dependencies and time-dependent interactions do exist which cannot be properly considered within the classical HRA approach. Since such dependencies and interactions may significantly affect the reliability assessment of human actions they ought to be taken into account within HRA. In the following sections some relevant dependencies and interactions are discussed.

2.1. Dependency of Human Reliability on Time Effects

One important aspect for assessing the reliability of a human procedure is to consider time-dependent interactions and stochastic influences (aleatory uncertainties). These may strongly impact the course of human actions which have to be accomplished and therefore affect the success of a human procedure. The time periods (required for conducting human actions) belong to those aleatory uncertainties which often do not get the necessary attention in the frame of HRA. The time period during which a specific action is accomplished will vary in general to a more or less degree, even if the same individual will perform the action. For that reason, the time periods required to conduct human actions have to be considered as random variables, i.e., they are subject to aleatory uncertainties.

The variability of time periods during which actions are accomplished affects the point in time when a requested procedure is accomplished. Therefore, the random variability of action times may have an important impact on the process behavior as well as on the reliability of the human procedure. This is due to the fact, that the reliability of a human procedure depends not only on the accurate execution of human actions but also on the fact that the required human actions are accomplished in time. This means, even if all actions are correctly performed, the procedure might still be effortless if the time period during which the procedure is accomplished exceeds a critical point in time. This is demonstrated by a simple example outlined in Figures 1 and 2. The example describes a situation where a valve has to be manually opened for pressure decrease. In Figure 1 the reliability of the human action is modeled without consideration of time effects.

In the situation depicted in Figure 1, the probability that the valve will be successfully opened is the sum of the probability p that the human action is conducted with no error and the probability $q \cdot p_1$ that an error will occur but the error is realized and corrected in a recovery action, i.e.:

$$P(\text{human action successful}) = p + q \cdot p_1 \qquad (1)$$

In contrary, the probability that the valve is not opened and hence, the human action is not successful is given by:

$$P(\text{human action not successful}) = q \cdot q_1 \qquad (2)$$

Figure 1. Reliability of human action without considering time dependencies

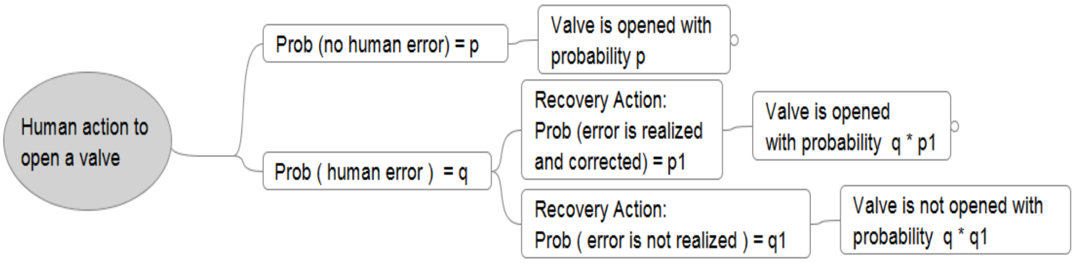


Figure 2 illustrates the situation if time effects are considered. t and t_1 characterize different points in time when the human action is accomplished and the valve is opened. t_{crit} denotes the critical point in time until the valve has to be opened in order to keep the underlying process in a controllable state. In general t_{crit} is determined by the underlying process. If the time period for conducting the human action is too long and exceeds the critical time t_{crit}, the further development of the process leads to an undesirable state and hence the human action is not successful. The effect of this situation on the reliability of the human action is outlined in Figure 2.

Figure 2. Reliability of human actions considering time dependencies

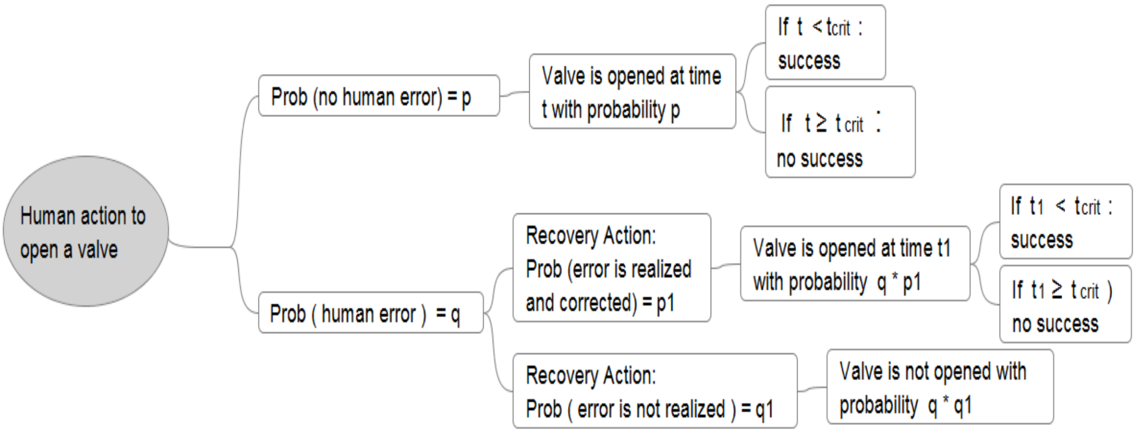


Figure 2 illustrates that the success of the human action is not only depending on the fact that the valve can be successfully opened but also on the point in time when it is opened. The mathematical explanation can be given as follows:

Assuming that t and t_1 are considered as random variables following corresponding probability distributions and t_{crit} are given; the probabilities of $P(t < t_{crit})$, $P(t_1 < t_{crit})$, $P(t \geq t_{crit})$ and $P(t_1 \geq t_{crit})$ can be calculated from the respective probability distributions resulting in the following:

$$P(\text{human action successful}) = [p + q \cdot p_1] \cdot P(t < t_{crit}) \qquad (3)$$

$$P(\text{human action not successful}) = q \cdot q_1 + [p + q \cdot p_1] \cdot P(t \geq t_{crit}) \qquad (4)$$

Comparing the success probabilities from Equation (1) and Equation (3) and assuming $P(t < t_{crit}) < 1$ it follows:

$$p + q \cdot p_1 > (p + q \cdot p_1) \quad P(t < t_{crit}) \qquad (5)$$

Equation (5) implies that the negligence of time effects in HRA systematically overestimates the reliability of a human action in those cases where $P(t < t_{crit}) < 1$.

Analogously, comparing the probabilities of ‘no success’ from Equation (2) and Equation (4) and assuming $P(t \geq t_{crit}) > 0$ it follows:

$$q \cdot q_1 < q \cdot q_1 + [p + q \cdot p_1] \cdot P(t \geq t_{crit}) \qquad (6)$$

Equation (6) implies that the probability of ‘no success’ is underestimated if time effects are not considered and $P(t \geq t_{crit}) > 0$.

These simple example shows that time effects represent an important aspect to be considered in assessing human reliability.

Another important reason to consider the time effects in HRA is the interdependency between conducting human actions and the underlying system process. Some actions which are conducted during a human procedure do have an immediate effect on the further development of the system process. Depending on the varying times when those actions are accomplished the development of the system process will also more or less vary. A different development of the system process may result in a different point in time of the critical value t_{crit}. In order to quantify those interdependencies the uncertainties of times when actions are accomplished have to be calculated. If these uncertainties are incorporated in the calculation of the system process, the probabilities $P(t < t_{crit})$ and $P(t \geq t_{crit})$ can be assessed.

Based on these reflections, GRS has developed a method (Crew Module) which allows modeling a human procedure as a dynamic event sequence. A main objective of the Crew Module is to assess the uncertainty of the point in time when a human action is accomplished which directly has an effect on the development of the system process. The uncertainty of times when an action is accomplished may depend on system states and on situations which might randomly arise in the course of the process of human actions. This will be further discussed in the following paragraph 2.2.

2.2. Dependency of Human Actions from System States and Aleatory Uncertainties

In this paragraph, interdependencies are outlined which might exist in human actions and therefore should be considered in the frame of HRA in more detail. Human actions do not only affect the system states, but system states may also affect the sequences of actions which have to be carried out in the given situation. In addition, human actions to be conducted may also depend on events randomly occurring in the course of time. Two examples are given for demonstration purposes:

Interdependency of human actions and system states
Assume a firefighting procedure where the shift fire patrol (FP) arrives at the fire compartment to check the location and state of the fire. In this situation, several actions are possible depending on the system state outlined in Figure 3.

Figure 3. Interdependency between human actions and system state

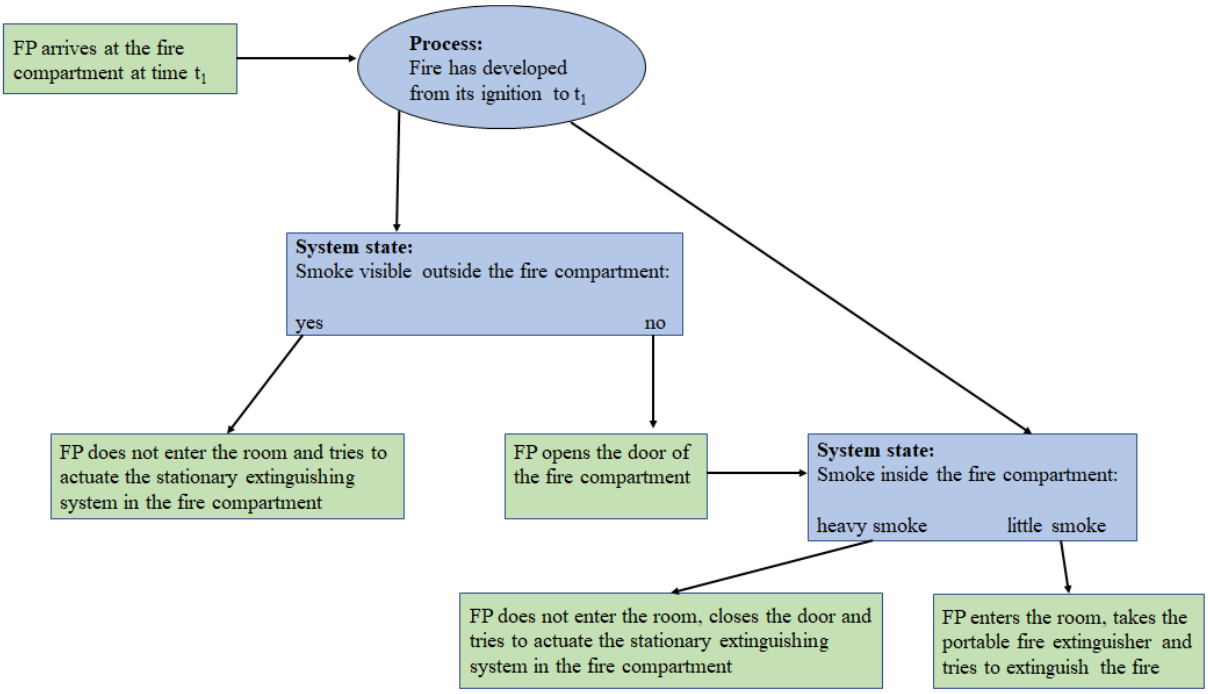


Figure 3 illustrates the following situation: The shift fire patrol (FP) arrives at the fire compartment at a time t_1 after fire ignition. The arrival time of FP is important because the fire develops from an incipient fire and develops during this time interval constituting the system state at t_1. The further actions of FP depend on the system state caused by fire development and propagation.

If no smoke is visible outside the fire compartment, FP opens the door to the fire compartment in order to check the state of the fire. If there is too much smoke in the fire compartment FP decides not to enter the room, closes the door and tries to manually actuate the stationary extinguishing system installed in the fire compartment. To manually actuate the stationary extinguishing system a valve located outside the fire compartment has to be opened. If there is no or little smoke visible in the fire compartment, FP enters the room, takes a portable fire extinguisher present and tries to extinguish the fire.

If the fire has already developed so far that smoke is already visible outside the fire compartment, FP does not enter the room and tries to manually actuate the extinguishing system from outside the fire compartment.

This example shows that the human actions FP will carry out differ completely depending on the system state which in this example is defined by the status of smoke inside and outside the fire compartment. It is emphasized that the system state may also depend on human actions. When FP arrives at t_1 it makes a big difference if t_1 is the time period between the arrival and fire ignition is short or long. If the time period up to t_1 is sufficiently short the fire has not yet developed from an incipient to a fully developed one so that there is a reasonable chance that FP can enter the fire compartment and extinguish directly the fire manually by means a portable fire extinguisher. If t_1 is too long, FP cannot enter the room and will try to manually actuate the stationary extinguishing system installed in the fire compartment or wait for the on-site fire brigade to arrive.

The time when FP arrives at the fire compartment represents a random value. The aleatory uncertainty of t_1 results from aleatory uncertainties of previous actions FP had to carry out as well as on random events affecting the actions to be accomplished. It is obvious, that the consideration of such interdependencies in HRA will affect the assessment of human reliability.

Dependency of human actions on aleatory uncertainties

To demonstrate the dependence of human actions on aleatory uncertainties the example of Figure 3 will be used. Given the situation where smoke is visible outside the fire compartment and FP does not enter the room. Instead he tries to manually actuate the stationary extinguishing system. The aleatory uncertainty which will affect the further actions of FP concerns the situation if the stationary extinguishing system can be manually activated or not. One cause that the stationary extinguishing system cannot be actuated is that the required valve to activate the spray is frozen and cannot be opened. If this aleatory uncertainty is taken into account in the analysis, different sequences of actions will arise which are illustrated in Figure 4.

Figure 4. Dependency of action sequences from aleatory uncertainties

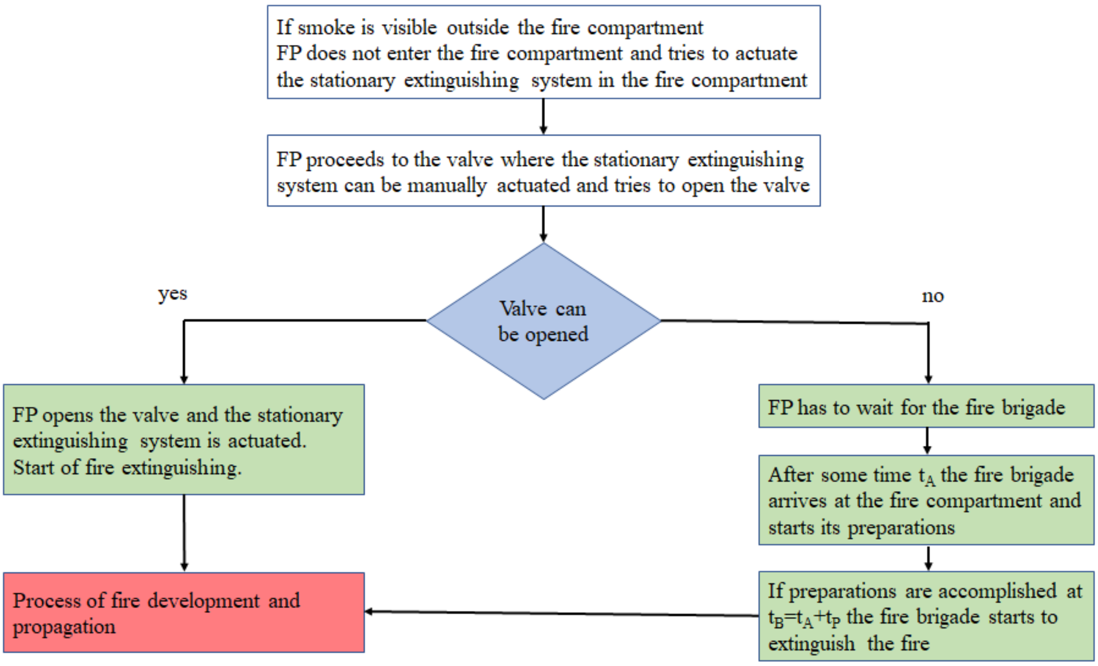


Figure 4 provides different action sequences depending on the stochastic event if the valve can be manually opened or not. If the valve can be opened (which will occur with a probability p), the stationary extinguishing system is actuated and starts to extinguish the fire.

In contrary, if the valve cannot be opened (with probability 1 - p), FP has to wait for the arrival of the on-site fire brigade. After some time period t_A the fire fighters from the on-site fire brigade arrive at the fire compartment and start their preparations with a duration t_P. It is emphasized that the time periods t_A and t_P are random variables according to the corresponding probability distributions. If the preparations of the fire brigade are accomplished (this will be after a time period $t_B = t_A + t_P$) the fire brigade starts to extinguish the fire.

The main difference between the two action sequences is that they will occur with a different probability and that they will differ in the point in time when fire extinguishing starts. The different fire extinguishing starting time points will affect the fire development and propagation as well as the time when the fire has been fully suppressed.

To account for the before mentioned dependencies, each action sequence depending on the outcomes of aleatory uncertainties or system states must explicitly be modelled in the Crew Module. While defining the action sequences, the times to accomplish single actions are generally considered as random variables. The general concept of the Crew Module is outlined in more detail in Section 3. In the following paragraph 2.3 those interdependencies of stress and human reliability are discussed which particularly may arise in the context of external and internal hazards.

2.3. Interdependency of Stress and Human Reliability in the Context of External and Internal Hazards

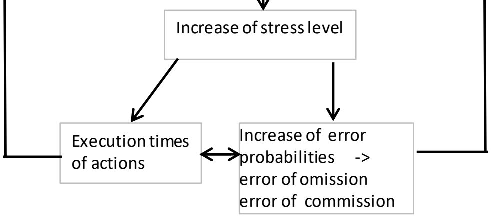
External and internal hazards may cause a variety of damages within a nuclear facility and often are accompanied by cascading effects. Cascading effects have multiple impacts on the plant which may induce different system failures and damages in the infrastructure. For many of these potential impacts, human actions are required in order to prevent, manage or mitigate the hazardous consequences arising from the hazards.

The main challenge arising in case of external and internal hazards is that those problems to be solved by the plant personnel are unfamiliar, unexpected and probably manifold. These unfamiliar situations constitute a more or less difficult problem to be solved by the plant personnel. For example, they have to solve problems under time pressure and aggravated conditions. Finding a solution to an unfamiliar problem heavily depends on the knowledge and experience of the personnel as well as on the complexity of the problem. In this case, rule-based human actions following well-trained instructions of procedures which have been thoroughly elaborated in advance are not applicable. More or less knowledge-based human actions are required finding a way to cope with the unknown situation. Knowledge-based behavior is a process where novel strategies of actions have to be generated and conducted to prevent or at least to mitigate adverse effects on safety.

A generic model for knowledge-based human actions has been developed at GRS and is outlined in [2]. This methodological approach considers knowledge-based behavior as a problem-solving process, because knowledge-based behavior and problem solving share essential features of generating and executing novel strategies of actions to mitigate adverse effects on plant behavior and hence to increase plant safety.

The highly demanding task of solving more or less complex problems within a limited time frame may increase the stress level of the personnel involved. The increase of the stress level of a person may affect the reliability of human actions. This can happen in different ways. On the one hand, higher stress may increase the probability of human errors. Human errors refer to failures of omission as well as to failures of commission. Failures of commission in turn may cause other system failures or further deteriorated plant conditions which in turn may further increase the stress level. On the other hand, higher stress may affect the time, during which necessary actions are accomplished. This will be caused by a mental blackout or panic-driven execution of an action which increases the probability of a human error. The interdependencies which may occur in case of external and internal hazards are outlined in Figure 5. The interdependency provided there suggests that stress is a dynamic quantity, the behavior of which depends on system conditions and the performance and success of past actions.

Figure 5. Interdependencies in case of external and internal hazards



In the following Section, a methodological approach is proposed which allows considering the aforementioned dependencies and interactions and tries to model human actions as a dynamic event sequence.

3. CONCEPT OF THE CREW MODULE TO SIMULATE HUMAN ACTIONS AS A DYNAMIC PROCESS

To overcome the ‘static’ view of the classical HRA approach, which is not capable to model such dependencies mentioned in Section 2 in an appropriate manner, a methodological approach has been developed by GRS aiming at modeling human actions as a dynamic event sequence. The advantage of this methodology is that time effects and dependencies of human actions from stochastic influences and system states can be modeled and analyzed in more detail. In addition, the method can be applied to model stress as a dynamic quantity which may increase or decrease depending on given situations.

The method is implemented in the so-called Crew Module, which can be coupled with MCDET [1] to perform a probabilistic dynamics analysis (Dynamic PSA) of a human procedure.

In contrary to the simulation of physical phenomena, the process of human actions cannot be defined by mathematical equations. For this reason it is necessary that a process of human actions which might depend on stochastic influences and system states must explicitly be described by event sequences.

The main concept of the Crew Module is to describe a complex human procedure as a sequence of more simple basic actions. In this context, a basic action is defined as a simple action which is executed by a specific person, e.g., operator X activates a control button, electrician Y goes from emergency feedwater building to the main control room (MCR). Basic actions can also be defined as communication actions, e.g., supervisor instructs operator X to carry out task A or operator X informs supervisor about the state of a component. The more detailed the complex procedure is described by basic actions; the more precisely existing dependencies of the procedure can be analyzed. For each basic action several attributes have to be specified:

- **Person who carries out the basic action**
  Basic actions should be defined in a way that one person can be identified who carries out the action.
- **Person or technical component affected by the basic action**
  Which person or component is affected, depends on the definition of the basic action. There are basic actions where no other person or technical components are influenced. For example, the operator goes from location A to location B. In that case, only the person who carries out the action is affected. Other basic actions might affect other persons or technical devices, e.g., if the basic action describes an instruction of the supervisor or an action where an operator switches off a pump. The specification of the person who is affected is important because it determines the point in time when the affected person can react according to the context of the basic action. The specification of the technical component which is affected by a basic action determines the point in time when the state of the given component is changed which affects the further development of the physical process.
- **Time needed to carry out the basic action**
  The time period for performing an action can be specified as a fixed value or as a random variable. In the latter case, a probability distribution has to be specified characterizing the aleatory uncertainty of the time needed to perform the action. In principle, each probability distribution can be used to specify the aleatory uncertainty of execution times. In cases where no information from the operating experience will be available, expert judgment is used to assess the aleatory uncertainty for the times needed to accomplish the specified basic action. Because the time period during which an action will be accomplished can be assessed more easily for simple actions than for more complex actions, expert judgment is supposed to work sufficiently well in this situation, because basic actions are supposed to be defined as simple actions in the Crew Module.

In order to assess the aleatory uncertainty of the duration of a basic action by expert judgment, generally a uniform distribution is used, where the expert has to assess the minimum and maximum time required to accomplish the basic action. If more information about the execution time is available (e.g., from operating experience) any other probability distribution can be used which fits the aleatory uncertainty best.

- **Description of the basic action**
  A brief description of a basic action is useful to understand the context of the basic action. This will be particularly helpful when the basic actions are composed to action sequences which constitute the model of the human procedure to be analyzed.

Beside the attributes of basic actions, other important features are used to model a human procedure in the Crew Module:

Definition of Branching Points
Branching points are used to define the dependency of action sequences on aleatory uncertainties. In order to define a branching point, a specific notation of a basic action is used.

Definition of Action Lists
Once all basic actions have been defined in order to describe a more or less complex procedure, the basic actions have to be arranged in so-called Action Lists. Action Lists are used to characterize a certain part of the procedure. Actions Lists can be used to specify different action sequences that depend on aleatory uncertainties or system states. For that reason, a condition must be specified for each Action List. An Action List is initiated in the simulation of the Crew Module when the corresponding condition of the Action List is given. It is therefore necessary that the conditions of the Action Lists are unique and that the system state can be checked after each time step. In order to meet this requirement the Crew Module is combined with MCDET.

The model of human actions including the necessary information of Action Lists and basic actions is created within a graphical user interface (GUI). A program has been developed reading the information from the GUI and automatically generating the input file for the Crew Module. Reading the input file the Crew Module simulates the model of human actions. The results of the simulation are analyzed by post-processing programs to assess probability distributions of those times when relevant actions are accomplished which affect the development of the system process.

To give an idea how a human procedure and its dependencies can be described in order to be modeled by the Crew Module, an example of a firefighting procedure is given in the following Section 4.

4. APPLICATION EXAMPLE OF THE METHOD TO A FIREFIGHTING PROCEDURE

In nuclear installations fire is an internal hazard which may have severe impact on items important to safety. This section demonstrates in which detail a firefighting procedure can be modeled and analyzed as a dynamic process using the Crew Module. The personnel potentially involved in firefighting are the shift leader (SL), the shift fire patrol (FP), the fire brigade leader (LFB) and the fire brigade members (FB). Although consisting of several people the fire brigade team is considered as one unit. It is assumed that the fire extinguishing system in place in the fire compartment is not automatically actuated as intended. Reasons may be a failure of the fire detectors or that the detection threshold of the detectors has not yet been reached. However, the stationary extinguishing system can be actuated manually by a valve located outside the fire compartment. In the following diagrams, some parts of the firefighting sequence are described in order to demonstrate what aspects can be modeled and analyzed by means of the Crew Module in combination with MCDET. To model the procedure as a dynamic process it has to be considered that the single actions of the personnel need a certain time (in general random times) to be accomplished, that some actions are carried out in parallel, and that actions may depend on process states and aleatory uncertainties.

The flow chart in Figure 6 demonstrates the first steps of basic actions of the firefighting procedure and indicates situations where communication between individuals, parallel performance of actions, and time dependencies are involved which considerably affect the further course of actions.

(1) After fire ignition, the firefighting procedure in a first step depends on the reliability of the fire detection and alarm system. In this example it is assumed that the fire detection and alarm system will work without failure, meaning that the alarm is indicated by least two fire detectors in the main control room (MCR). If there is an alarm by only one detector it might be a spurious alarm. In this case, FP is instructed to go to the fire compartment and check if there is a fire. Only if the fire is verified, LFB and the team members of the FB are alarmed. If the fire detection and alarm system fails, no alarm is signaled in the MCR. In this case, the fire can only be detected, if FP randomly visits the fire compartment and detects the fire during his routine inspection. In this example, the procedure is described in case the alarm system works without failure. If no or only one detector give a fire alarm, the corresponding action sequences have to be described in a similar way.

(2) Each box in the sequence can be regarded as a basic action with a corresponding time period during which the action is assumed to be accomplished. The actions which are described in this part of the firefighting procedure include communication between the personnel involved. When SL alerts the personnel, e.g. via pager and loudspeaker system, the reactions of the different individuals are performed in parallel. In the diagram this is indicated by parallel sequences of actions performed by LFB, FP and the FB team members, respectively.

(3) Since the times when LFB and FP realize the alarm, read and interpret the information on the pager and try to call SL in the MCR are random variables, the further process depends on the time who of both (LFB or FP) is first to inform SL by phone.

Figure 6. Initial phase of the firefighting process involving communication between individuals and time dependencies of the process

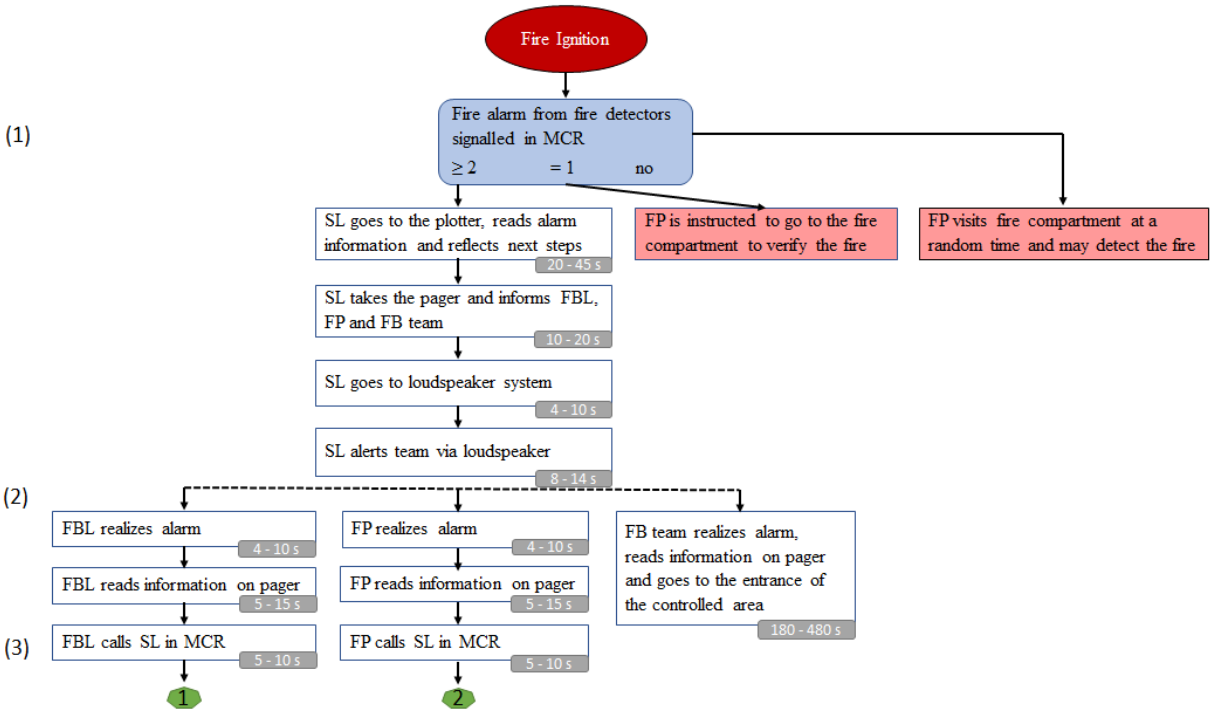
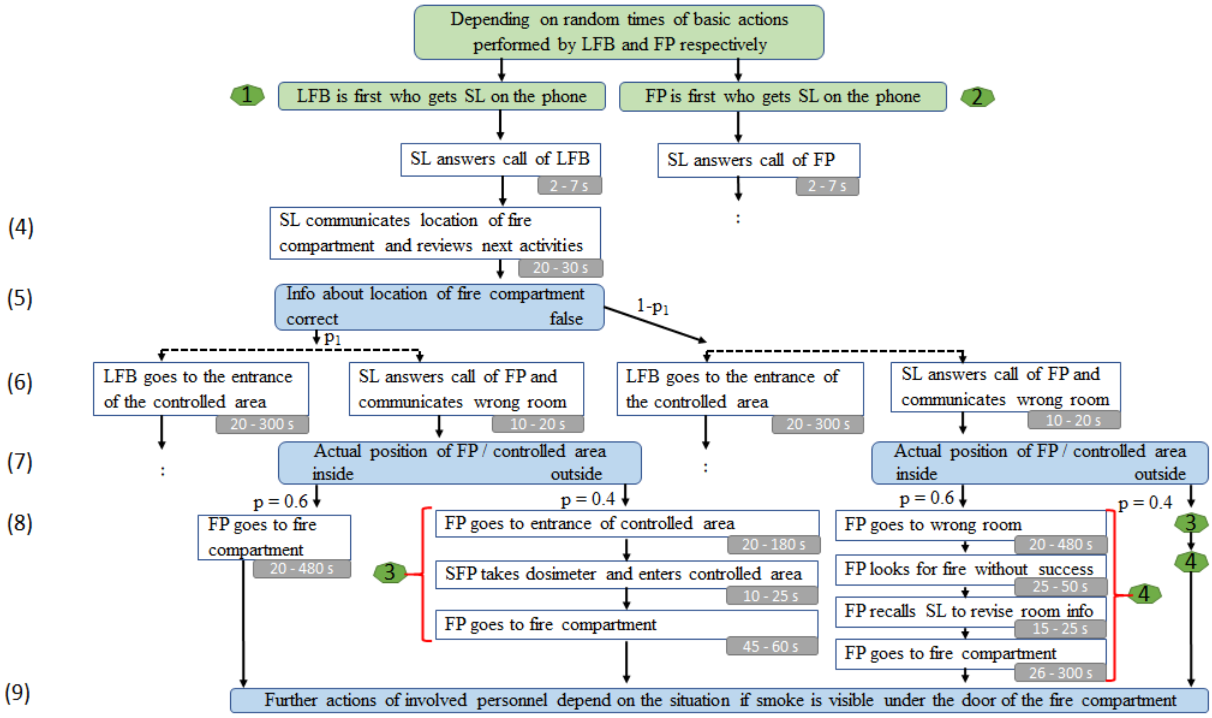


Figure 7 illustrates the action sequence in case that LFB is the first who informs SL by phone (indicated by the green box 1). In this case, SL communicates the location of the fire compartment to LFB and both review the next activities to be performed. In the other case (green box 2) where FP is the first who calls the SL, FP will get the information first and is able to go to the fire compartment at an earlier point in time. This situation is an example where the further action sequence depends on time effects of actions performed by different individuals.

Figure 7. Part of the firefighting process depending on aleatory uncertainties concerning errors of commission and random position of FP when receiving information of fire compartment



(4) When SL communicates the location of the fire compartment a human error might occur. The human error might be due to different causes. First, SL mistakenly notes a wrong room number and therefore communicates a wrong room location to both LFB and FB. This would imply that both will go to a wrong room where no fire can be detected. Second, either LFB or FP may misunderstand the information provided by the SL. In this case, only one of them is initially going to a wrong room while the other goes to the actual fire compartment.
In Figure 7 only the first case is modeled for demonstration purposes. The false notation and communication of the wrong location of the fire compartment can be regarded as an error of commission.

(5) The correctness of information about the location of the fire compartment represents an aleatory uncertainty (blue box). The probabilities of the possible outcomes that the location of the fire compartment is correctly (p_1) or falsely ($1 - p_1$) communicated by SL may be assessed, e.g., by using THERP [3].

(6) For each discrete outcome of the aleatory uncertainty (correct or false information) a separate sequence of actions has to be modeled due to the different conditions caused by the outcomes of the aleatory uncertainty. In case SL has communicated the correct location of the fire compartment LFB moves to the entrance of the controlled area where he will meet the on-site FB team. Depending on the actual location of LFB in the plant he may need more or less time to go to the entrance of the controlled area. The uncertainty about the location of LFB is expressed by a uniform distribution between 20 s and 300 s. The further basic actions of the FB and LFB, which are not further described in Figure 7, concern the way to the fire compartment where they start their preparations and start to extinguish the fire.
In parallel and as soon as SL has finished the call to LFB he will answer the call of FP and communicate the corresponding information. Up to this point in time the same actions will also be performed if the information on the fire compartment location is wrong.

(7) In the following, only those actions of FP are further characterized which depend on the location of FP within the plant at this point in time. Since his actual location is a random variable, the FP may be inside or outside the controlled area when he receives the information from the SL. The probabilities may be assessed by using plant-specific information, e.g., from information of the work plan of the FP during his shift. As the assumed fire compartment is inside the controlled area located nearby the entrance and the controlled area is rather large, the random position of FP has an effect on the time FP will need to arrive at the actual fire compartment.

(8) In case FP has received wrong information on the fire compartment he initially will go to the wrong room, will try to find the fire (unsuccessfully) and recall SL to check the room information. In this situation it is assumed that SL will realize and revise his mistake. Only then FP will receive the correct information and go to the actual fire compartment assuming that the revised information of SL will be correct. All these additional actions will affect the time when FP will arrive at the fire compartment.

(9) As soon as FP arrives at the actual fire compartment the further actions will depend on the process state of the fire. This has already been discussed above in Section 2.2 (see Figure 3).

This kind of description of a human procedure (which is partially illustrated in Figure 6 and Figure 7) depending on time effects, process states and aleatory uncertainties (of any kind and not only of human errors) can be modeled and simulated by means of the Crew Module in combination with MCDET. MCDET is used to handle the aleatory uncertainties and to generate a sample of dynamic event trees. The dynamic event trees are analyzed for calculating probability distributions of the time when important actions are accomplished. An example is the point in time when FP arrives at the fire compartment. This time is relevant, because the fire has developed up to this point in time and constitutes a condition which may impact further actions.

This example of a firefighting procedure as part of mitigating an internal hazard will be used to demonstrate that the method of the Crew Module is also appropriate to model cognitive factors such as stress as dynamic quantities. In this example, the stress situation will occur if the FP gets wrong information and initially goes to a wrong location. Due to loss of time the stress level of the FP may increase. The next step of work is to demonstrate how stress is involved in modeling the firefighting procedure as a dynamic quantity and to analyze its effect on the firefighting procedure.

5. CONCLUSIONS AND OUTLOOK

In the analysis of human actions many dependencies and interactions exist which ought to be considered in the frame of HRA, because they may significantly affect the assessment of human reliability. Relevant aspects are the dependency of human reliability not only on human errors but also on time effects, dependencies of human actions on system states and aleatory uncertainties and the interdependency of stress and human reliability.

Many of these dependencies cannot be properly considered within the classical approach for HRA. For that reason, new methods are required for modeling such dependencies and interactions as precise and realistic as reasonably possible.

In order to overcome the ‘static’ view of the classical HRA approach, a methodological approach has been developed by GRS aiming at modeling human actions as a dynamic event sequence. The advantage of this methodology is that time effects as well as dependencies of human actions on stochastic influences and system states can be modeled and analyzed in more detail. The method has been implemented in the Crew Module, which can be coupled with MCDET to perform a Dynamic PSA of a human procedure. For demonstrating which kind of human actions can be modeled and simulated by the Crew Module a demonstration example of an internal hazard is given. The example is used to provide an idea in which detail dependencies and interactions of a firefighting procedure can be modeled and simulated as a dynamic event sequence applying the Crew Module.

The dynamic analysis of human actions is particularly important because it enables the consideration of time effects and dependencies allowing a more detailed analysis and a more credible assessment of human reliability.

The next step of enhancing and extending the methodological approach is to incorporate stress as a dynamic quantity into the model of the firefighting procedure. To model stress as a dynamic quantity means that stress will increase or decrease depending on given situations. Simulation results will be used to analyze the influence of stress on the firefighting procedure.

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