An extended version of the Dynamic Safety Model to analyse the performance of a medical emergency team

Thierry Morineau[1], Cécile Isabelle Bernard[1], & Seamus Thierry[2]
[1]University of Bretagne Sud, Vannes
[2]Scorff Hospital, Lorient
France

Abstract

The Dynamic Safety Model (DSM, Rasmussen, 1997) constitutes an original approach to safety issues. The model posits that adverse events are caused mainly by pressures coming from work constraints that lead operators' activity to migrate towards unacceptable limits of performance. In particular, Ramussen calls attention to the economic and workload pressures exerted on activity, insidiously pushing operators to tolerate risky behaviours as long as no critical event occurs. Recently, Morineau and Flach (2019) proposed to extend the DSM in order to integrate this model fully into the Cognitive Work Analysis (CWA) framework. More precisely, they suggested that the work domain analysis, the first stage of CWA, be replaced by the DSM. This use of the DSM would enable the analysis of intentional work systems involving loose coupling between work domain and organization. From this perspective, we present an analysis of the activity of a medical team confronted with a medical adverse event simulated in an emergency room.

Introduction

Research in cognitive systems engineering has developed a formative approach to analyse work systems. The basic assumption of this approach is that operators' behaviours are mainly shaped by work constraints, in the same way as animals in an ecosystem must adapt their behaviours to environmental features. At the methodological level, Cognitive Work Analysis (CWA) is the framework commonly used to describe behaviour-shaping constraints (Rasmussen, 1986; Vicente, 1999). It involves five embedded stages of analysis, namely work domain analysis (WDA) describing the constraints arising from the objects (domain) on which the work is performed; control task analysis describing constraints produced by the requirements to perceive and act on the work domain features; strategy analysis describing how performing tasks can be embedded in specific strategies, notably to manage the workload; organizational analysis focusing on workload allocation between human and/or artificial agents; and competencies analysis focusing on the individual inner constraints required to perform tasks.

Numerous studies have shown the relevance of CWA to apprehend work systems (e.g. nuclear plant, aviation, anaesthesia). Some studies indicate that this approach fits

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particularly well with the analysis of causal work systems in which the work domain constraints directly drive the other embedded work constraints: tasks, strategies, team organization, and competencies (Hajdukiewicz et al., 1999; Wong et al., 1998). In a causal system, a tight coupling exists between work domain and work organization. In an intentional work system, outcomes particularly depend on how work is organized by operators through ad hoc decisions on priorities and adaptive processes to cope with the workload. In intentional systems, relationships between the work domain and the organization are mainly loosely coupled. Hence, in an intentional work system, a major issue for operators is to ensure efficient management of work constraints by coordinating the work requirements. This coordination will ensure that the organization's activity stays synchronized with the requirements imposed by the work domain state.

To analyse loosely coupled work systems, Morineau and Flach (2019) have proposed a new version of CWA, named "heuristic Cognitive Work Analysis" (hCWA). The specificity of this method resides in replacing the first stage of work domain analysis with a more modest, but heuristic, modelling of work constraints based on an extended version of the Rasmussen's Dynamic Safety Model (DSM). After outlining the DSM, we introduce hCWA and a first application on observations collected during medical emergency scenarios simulated in a high-fidelity simulation setting.

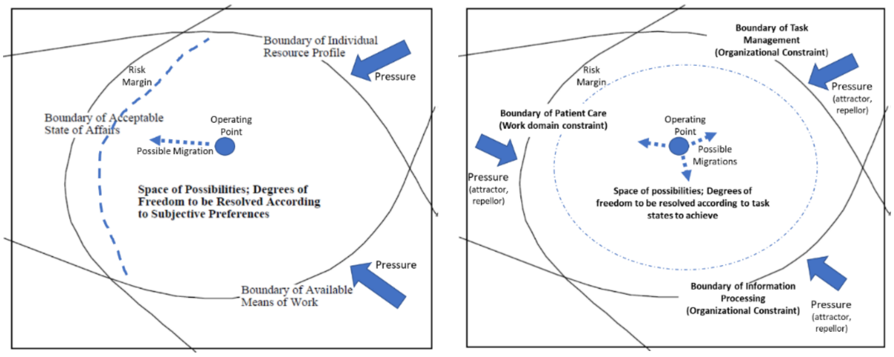
The Dynamic Safety Model

The level of coupling of a work system with its work environment constitutes the cornerstone that led Rasmussen (1990) to propose the DSM as a framework to analyse performance and safety issues. The tighter this coupling is, the more dependency relationships exist between events occurring in the work system.

At the lower level of human-machine interaction, tight links exist between operators and the work environment. Operators rely on the deterministic sequence of behaviours that the machine induces by its sequence of operations. At this level of granularity, sequential task analysis methods can be used to describe how users' behaviours more or less follow expected sequences, considering that deviations potentially represent less efficiency, error, or accident.

At the higher level of socio-technical systems, tight coupling can also be prominent if the work organization is based on a traditional way of working, whereby work processes are strictly decomposed as a set of sequences of discrete states to be reached. In this context, traditional accident analysis based on causal trees can be used to determine at which step operators violated some expectations, which led to the final accident or failure.

However, in modern work systems, automation or high demands of flexibility in activity provide operators with more degrees of freedom. At a high level of automation, the operators' job is to supervise automatic systems. When high flexibility in the work process is requested, the operators need to find ad hoc solutions. These degrees of freedom lead operators to use frequent decision making and implement adaptive strategies. Hence, the basic issue for operators is how to resolve numerous degrees of freedom in a space of possibilities bounded by a set of work constraints that need to be complied with. In this space of possibilities, operators' activity can be modelled as an operating point with a trajectory in a workspace bounded by work constraints. This is the core of the DSM proposed by Rasmussen (Figure 1).



Figures 1 and 2: A synthesis of the Dynamic Safety model inspired from Rasmussen (1990 & 1997, left side) and its extended version used in hCWA and applied to healthcare systems inspired from Morineau and Flach (2019, right side)

Rasmussen has proposed different versions of the DSM. In his 1990 paper, Rasmussen presented the constraining boundaries as respectively referring to the "state of affairs" that corresponds to the state of the work domain, the "available means of work" (e.g. equipment), and the "individual resource profile", which is composed of operators' physiological and psychological capacities. These work constraints can produce pressures on operators that can potentially lead their trajectory to cross a boundary, leading to an accident or a problem. Based on these generic constraints, Rasmussen (1990) suggested to model activity respectively by identifying the space of possibility specific to the analysed work system, the subjective criteria used by operators to make decisions in order to solve degrees of freedom in their trajectories, the strategies used to synchronize with the work constraints, and the team organization aspects and the competencies needed to move the operating point within the workspace.

In comparison with this first generic approach to the workspace that potentially allowed it to be used as a sketch for analysis in relation with CWA, Rasmussen went further in the specification of the DSM in his 1995 and 1997 papers. The constraining boundaries were specified as referring to acceptable performance (firstly named "acceptable state of affairs"), economic cost, and individual workload. Organizations seek to limit the economic cost of activity and operators, their level of workload. The combination of these two pressures may critically and insidiously lead the operating point to migrate towards a single safety margin located near the acceptable performance boundary. To reduce this risk, proposals in safety science can be deployed to increase the safety margin by augmenting the work system reliability, increasing the operators' awareness of this risk, for instance through a safety management culture, or by making the boundary more visible, for instance with the ecological interface design (Vicente & Rasmussen, 1992).

In Cook and Rasmussen (2005), the DSM was used to interpret safety issues in hospitals. Through this modelling, the authors returned to the basic issue of model emergence by considering what happens if an adaptive modern work system uses tight coupling.

Heuristic Cognitive Work Analysis (hCWA)

Heuristic Cognitive Work Analysis is a methodological framework that is based on the first approach to the DSM proposed by Rasmussen (1990). The DSM is viewed as having a heuristic value for CWA. In hCWA, the first CWA stage of work domain analysis through an abstraction hierarchy is replaced with the DSM template. Rather than expanding the description of the work domain through an abstraction hierarchy that is particularly well-adapted for causal work systems, hCWA proposes to focus on the dynamics of activity triggered by the necessity to coordinate multiple conflicting constraints arising from the work domain and the organization, with multiple degrees of freedom to resolve in order to find the best adapted trajectory in the space of possibilities.

Figure 2 shows the extended version of the DSM used in hCWA that is specifically applied to medical work systems. Previous research has identified the following three constraints as specific to healthcare systems (Morineau et al., 2017):

- *Patient Care* is the work domain constraint for a healthcare system. Potentially, a patient can evolve towards a deteriorating state, thus putting pressure on the medical team;
- *Task Management* is an organizational constraint. It involves the manipulation of drugs and equipment during care delivery. These elements induce the performance of specific tasks to prepare, control, restore, or store them. To manage drugs and equipment is a peripheral activity for professionals who have been educated and trained mainly to deliver care. However, if these tasks are not performed well, they will produce risky pressure on activity;
- *Information Processin*g represents the cost involved in processing information that is exchanged between operators and/or with information systems. Research in distributed and situated cognition has shown that much information processing and storage is performed in the work environment rather than exclusively in individuals' minds (Hollan et al., 2000). Similar to task management, information processing involves resources used to adapt to the work domain constraint (care delivery), but it can also represent a supplementary constraint for the cognitive workload, requiring communicating, reading and writing digital or paper documents. Difficulties or noise in information processing can drastically weaken operators' activity.

All these constraints can function as attractors or repellors for operators; concretely, they may lead to avoidance (repellors) or attraction (attractors) in the course of activity. Contrary to the original version of the DSM, all the work domain constraint can exert pressure on trajectories in the space of possibilities; thus, several forms of migration towards risky margins can occur inside the workspace. Facing these three basic work constraints, operators need to use their inner resources to manage the trajectory of their operating point in the workspace.

In hCWA, the DSM identifies the problem operators need to solve. Modalities to solve this problem can be found in the next analysis stages of CWA, namely control task, strategies, work organization, and competencies analyses.

Analysis of simulated medical emergency events with hCWA

We analysed two episodes of care delivery simulated in a high-fidelity simulation room: handoff and bed lowering to facilitate cardiac massage. The patient was represented as a realistic and interactive mannequin, including physiological parameters accessible on a monitor. Participants were professional nurses and nursing aids in the context of training sessions (more details can be found in Morineau & Flach, 2019).

Episode #1: Handoff and patient monitoring

This first episode occurs at the beginning of the session, when nurse N1 performs the handoff with nurse N2 and nursing aid NA1. Four main events can be identified that describe the trajectory of the operating point in the workspace according to the attracting or repelling forces induced by the constraining boundaries: Patient Care, Task Management and Information Processing (Figure 3):

1. Handoff at the entrance of the bedroom: Information processing attraction.
2. Call from the patient who is stressed: Patient care attraction;
3. The caregivers continue the handoff around the patient's bed: Patient care attraction despite the necessity to perform the handoff;
4. Nurse1 interrupts Nurse2 who was explaining stressful details of the next analysis to the already stressed patient: Patient care as repellor. Nurse2 must avoid to speak in front of the patient.

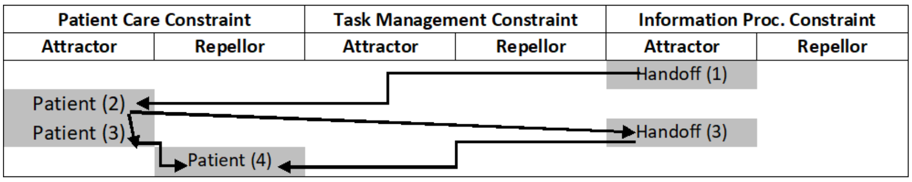


Figure 3. Trajectory of the operating point during Episode #1 regarding the pressures exerted by the three boundaries: Patient Care, Task Management, Information Processing.

Episode #2: Lowering the bed and performing cardiac massage

This second episode covers the difficulties experienced by NA1 to lower the top part of the patient's bed with the remote in order to facilitate the current cardiac massage. Ten main events can be identified (Figure 4):

1. Nursing Aid1 wants to lower the bed. First, she wrongly raises the bed, then rapidly succeeds, but fails to lower the top part: Attraction from task management.

2. Nurse2 says: ‘You must lower the bed’ and pushes directly on the top part of the mattress, without any success.
3. NA1 takes the remote but fails to lower the top part of the bed.
4. NA1 assists her teammate to place the massage board under the patient.
5. NA1 tries to lower the top part of the bed again, but instead produces a new lowering of the entire bed.
6. NA1 asks N2: ‘Can you lower the bed, please!’
7. N2 lowers the bed while regulating the oxygen flow: Both patient care and task management exert an attraction.
8. While she is massaging, NA1 asks N2 ‘Again, please’.
9. N2 says: ‘It is at the max.’: Bed management is considered as a repellor by the nurse.
10. While waiting for defibrillation, NA1 succeeds in lowering the bed: a waiting stage in patient care is used for bed management.

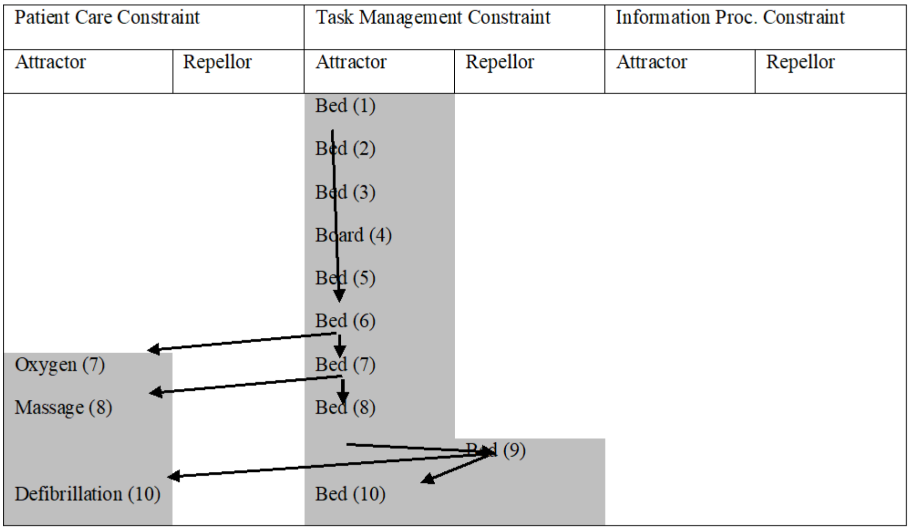


Figure 4. Trajectory of the operating point during Episode #2 regarding the pressures exerted by the three boundaries: Patient Care, Task Management, Information Processing.

In these two episodes, the caregivers engage resources in terms of task control, strategies, work organization, and competencies.

Task control

Task control refers to an adaptive process based on control loops (e.g., regulation, exploration, anticipation) to coordinate the work constraints. In this context, the normative descriptions of tasks through instructions and procedures can be considered as landmarks to assist implementing these control loops and to avoid violating the risk margins.

Episode 1: The handoff represents an anticipatory process. This process is interrupted and modified by the stressed patient, which triggers regulations among caregivers by responding to the patient's questions and filtering the information communicated to the patient, when N2 stops N1 in her description of details concerning the clinical examination that will be endured by the patient.

Episode 2: A global loop of exploration is engaged by NA1 to work out how to lower the bed with the remote during the highly critical moment of cardiac massage. Failures lead to a set of regulations inside this exploration loop, with the support of N2.

Strategies

Strategies to perform tasks in loosely coupled work systems involve balancing priorities and values in order to manage the workload. Selecting between possibilities of multitasking or sequential task performance must be made rapidly.

Episode 1: First, a sequential activity begins during handoff, then the necessity to manage the patient's interruptions leads to a multitasking configuration of work beside the patient's bed.

Episode 2: This episode is markedly interrupted, which leads to multitasking through time-sharing, when NA1 stops care delivery and tries to lower the bed and when N2 tries to lower the bed to assist NA1, or through parallel activity, when N2 lowers the bed and regulates the oxygen flow.

Work organization

Work organization concerns allocation and redistribution of the workload among teammates. It also refers to the spatial and temporal organization of the work environment with the purpose of reducing the workload.

Episode 1: This episode addresses the issue of where and how the handoff must be performed. Integrating the patient into the handoff becomes problematic.

Episode 2: This episode deals with the need to engage the maximum of human resources on patient care, instead of being occupied in trying to lower the bed. Ergonomic solutions to simplify this action upon the patient's bed could be proposed.

Competencies

Expertise allows operators to decrease the workload involved in their adaptive processes to work constraints, notably through changes in their level of cognitive control; these changes can be based on knowledge (mental model), rules (heuristics), or skills (Rasmussen, 1986).

Episode 1: Handoff mainly involves knowledge-based behaviours through the communication of a mental model of the situation to the next team. This level is particularly sensitive to interruptions that can lead to omissions in the handoff content.

Episode 2: Performing cardiac massage is a motor skill that demands considerable physical effort and requires caregivers to adopt a specific posture in order to perform a successful massage. Using the bed remote involves a rule-based control of behaviour: users need to know how to use the device. If the functioning rules are complex, operators will forget them, as occurred in this episode.

Conclusion

In Cognitive Systems Engineering, some concerns about the possibility of applying CWA on intentional low coupled work systems have been raised (Wong et al., 1998). Low coupled work systems are governed mainly by constraints emerging from the ways operators organize their work and find solutions to resolve the multiple degrees of freedom that they must deal with.

By considering the constraints arising from both the work domain and the work organization, hCWA proposes an alternative to the traditional CWA that is focused on the work domain constraints. It could deal with the ergonomic issues posed by intentional work systems. hCWA is a heuristic analysis framework since it searches for the basic work requirements that structure the work system and fundamentally shape the operators' behaviours. Rather than describing exhaustively the work domain properties, as the abstraction hierarchy technique does, hCWA points out the consequences of the conflicting interactions between the basic work constraints. These interactions must be dynamically solved by operators in the course of their activity. Such an analysis could be put in relation with the notion of 'elementary structure' developed by the anthropologist Claude Levi-Strauss (1945) or the notion of 'simplexity' proposed by the physiologist Alain Berthoz (2009).

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