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WORK DOMAIN ANALYSIS FOR INTENTIONAL SYSTEMS

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Work domain analysis (WDA) is an approach developed by Rasmussen (1985) for representing the structure of complex work environments. Many examples of the approach have surfaced in the literature, predominantly of physically coupled causal systems (e.g., process control). For causal systems, the environment is strongly constrained by the laws of nature. This approach can also be used for representing intentional systems (e.g., military command and control), although there is some controversy on this issue. For intentional systems, the environment is strongly constrained by actors' intentions, values, and priorities of practice. This paper discusses the differences between causal and intentional systems and provides direction on how to proceed with a WDA for intentional systems. A WDA is presented for emergency ambulance dispatch management and military command and control to illustrate the approach. Finally, a discussion of the implications and future research recommendations are presented.

INTRODUCTION

Work domain analysis (WDA) has been applied to many systems with various characteristics (e.g., process control, petrochemical, aviation, medical, library information retrieval) (Vicente, 1999). While there have been numerous examples of these analyses, most have been performed on physically coupled causal systems that are predominantly constrained by the laws of nature (e.g., Vicente & Rasmussen, 1990; Burns, 1998). This analysis technique may also be applied to intentional systems (i.e., systems that are generally structured by user intentions, rules and practices), although there are relatively fewer examples (e.g., Rasmussen, Pedersen, & Grønberg, 1987; Moray, Sanderson, & Vicente, 1992). However, there is some controversy on this issue and some researchers have advocated that WDA cannot be used for representing intentional systems (Wong, Sallis, and O'Hare, 1998). In their paper, Wong et al. state: "the approach appears not suited for use in human-activity-based intentional systems domains… these cause-and-effect relationships between the anomaly simply cannot be traced via the structural invariants identified through the work domain analysis" (pp. 150).

The purpose of this paper is to demonstrate how a WDA can be used for analyzing intentional systems. First, we discuss the general characteristics of intentional systems and how they can be different from causal systems. Second, we discuss the approach for structuring intentional systems, with a WDA for emergency ambulance dispatch management and military command and control. For each example we present a work situation to demonstrate how specific parts of the work domain structure can be used for problem solving. Finally, we discuss some implications and future research directions.

STRATEGIES FOR CONDUCTING A WDA

In order to develop a strategy for conducting a WDA, it is useful to first determine the characteristics of the work environment, and purpose and scope of analysis. This may help to establish the boundaries for the WDA and provide insight into deciding which constraints to include in the analysis and how they can be modeled using the framework.

Different types of constraints can co-exist in the same work environment. Rasmussen, Pejtersen, and Goodstein (1994) outline a taxonomy for characterizing work environments based on the relative degree of intentional and causal constraint. Figure 1 outlines a modified form of this taxonomy for a few work environments of the power generation industry mapped onto different locations on the continuum, with different purposes and scopes of analysis.

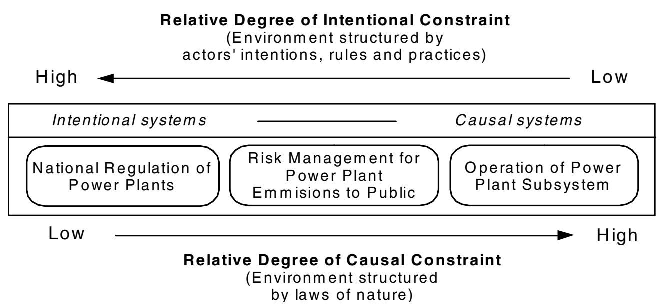

Figure 1: Characteristics of work environments based on the relative degree of intentional and causal constraint (adapted from Rasmussen et al., 1994).

There are two coupled axes in Figure 1, the relative degree the work environment is structured by intentional constraints (i.e., actors' intentions, values, and rules and practices) compared with causal constraints (i.e., the laws of nature). Work environments fall somewhere along this continuum. The specific location is highly dependent on its characteristics, and purpose and scope of analysis. For example, if a designer is interested in developing a new human-computer interface for a specific part of a physically coupled power plant for the purposes of supporting monitoring and control by an operator, the WDA would focus primarily at modeling the causal constraints of that environment. These constraints will have a stronger influence

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on shaping behavior for the identified purpose. However, if the purpose of analysis is changed to designing a work system for minimizing the risk to public health and safety from plant emissions and the scope now includes the power plant, a defined geographic region surrounding the plant, and resources to manage this risk, the WDA analysis would focus more on modeling the intentional constraints and less on the causal constraints. Priority criteria and measures of risk could be introduced into this analysis. Finally, if the purpose of analysis and scope are now changed to designing an organizational structure for regulating power plants at a national level, the WDA should focus primarily on modeling intentional constraints. Regulatory requirements, public policy, and rules of practice could be introduced in this analysis.

Thus, it is important to consider the characteristics of the work environment, and purpose and scope of analysis before conducting a WDA. These factors may have a strong influence on the appropriateness and outcome of the analysis. Once these factors have been considered, a WDA may proceed. In the next section of this paper, we discuss how a WDA can be conducted for intentional systems (i.e., systems with a relatively high degree of intentional constraint). Two examples are presented: emergency ambulance dispatch management and military command and control.

WDA FOR EMERGENCY AMBULANCE DISPATCH MANAGEMENT

A work environment to illustrate how a WDA can be conducted for an intentional system is emergency ambulance dispatch management (EADM). A description of this work environment is presented in Wong et al. (1998). The purpose of Wong et al.'s analysis was to design interfaces that support operational level EADM. In this work environment, the dispatch center has a team of operators that manage a network of distributed resources (e.g., ambulances) to handle emergencies within a particular geographic region. This is an intentional system because the work environment is constrained by values, priorities, and rules and practices (e.g., management of emergencies according to an acceptable level of risk). The boundaries meaningful for dispatch management include both the response resources and emergencies, embedded within the environment. There are also causal constraints that are important to model (e.g., balance and function of emergency response resources). These constraints co-exist in the same work environment.

Wong et al. (1998) initially conducted a cognitive task analysis (CTA) of this work environment. They reinterpreted their CTA findings to develop a work domain representation by conducting a WDA. Their work domain structure had five levels of abstraction: goal, priorities, functions, processes, and objects. Within their work domain representation, they identified both activities (e.g., locate nearest available ambulance) and means-ends relations of the EADM center. They concluded that the WDA did not capture all the aspects required for problem solving in the work environment and thus the approach cannot be used for analyzing intentional systems. However, considering the factors discussed in the previous section, Wong et al. did not choose a wide enough scope for their WDA, based on the characteristics of the work environment and purposes of analysis. An appropriate scope would include characteristics of the geographic region, emergencies, and response resources (including functional capabilities and limitations), which Wong et al. (1998) mention are "outside the system" (pp. 150).

In the analysis presented in this section, we have used the same work environment description, but performed a preliminary WDA separately. The results of our analysis are different from the analysis of Wong et al. (1998), and we show that WDA can be conducted for intentional systems. Our analysis includes the modeling of intentional constraints that were deemed appropriate based on the purpose of analysis previously outlined and wider scope of analysis compared with that of Wong et al. (1998).

Figure 2 provides the general structure of our preliminary WDA for EADM using Rasmussen's (1985) abstraction hierarchy. The structure follows a similar one introduced by Rasmussen et al. (1987) for emergency management in non-nuclear industries, and Moray et al. (1992) for emergency management in the nuclear industry.

Level of Abstraction	Domain of Potential Risk	Domain of Mitigation Resources
Functional Purpose	Goal: Maximize emergency health care response given the level of risk that is acceptable; Constraints: The resources and abilities associated with the emergency response system	
Abstract Function	Priority criteria and given level of acceptable risk (e.g., survival, damages, public opinion, costs, rules and regulations)	Time, resource balance within region, probability of successful treatment
Generalized Function	Urgency of injury	Transportation, quality of care
Physical Function	Functional impairment, consequences of injury	Functional capability of resources (e.g., qualifications of medical personnel, speed of ambulance)
Physical Form	Location, # of people injured, type of injury	Locations, inventories, availability of various response resources (e.g., helicopters, ambulances, stations, hospitals, command posts, paramedic officers), roads, weather, terrain, traffic

Figure 2: Preliminary abstraction hierarchy for EADM (adapted from Rasmussen et al., 1987).

The work environment was divided into two "object worlds", domain of potential risk associated with identifying, assessing, and prioritizing emergencies (i.e., constraints on risk identification, analysis, and assessment), and domain of mitigating resources associated with the capabilities and limitations of the response resources (i.e., constraints on risk management). Dividing the work environment into two "object worlds" provides a way of distinguishing the risks in the environment (i.e., emergencies) and resources available to manage those risks (i.e., response resources). The work environment is also divided into various levels of abstraction, with the lower levels providing the means for achieving the higher level purposes. The dispatcher will need information about both aspects of the work environment and various levels of abstraction to dynamically make decisions on the allocation of resources and prioritization of emergencies.

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The domain on mitigation resources identifies the capabilities and limitations of the emergency response system. The physical form level identifies the appearance, condition, location, and spatial relationships of the response resources in the environment. The physical function level identifies the functional capabilities and limitations of these resources to handle emergencies. The generalized function level identifies the overall abilities for transportation and quality of care based on the functional capabilities and limitations of the resources. The abstract function level identifies the constraints associated with prioritizing resources including the probability of successful treatment, arriving at the emergency location within a particular time, and balancing resources across the geographic region. The functional purpose level identifies the purposes of the EADM work environment, to maximize emergency health care response given an acceptable level of risk and constraints associated with the response resources.

An analogous representation may be formed for the domain of potential risk, which structures the risks and value judgements associated with emergencies in the region. The physical form level identifies the emergencies in terms of location, appearance, and condition of injured people in the environment. The physical function level identifies the functional impairment and consequences of the injuries. The generalized function level identifies the level of urgency associated with the functional impairment and consequences. The abstract function level identifies the criteria for prioritizing the emergencies (e.g., risks associated with survival and damage). The functional purpose level is the same as for the domain of mitigation resources.

Next, an example of how the work domain structure can be used for evaluating and managing particular work situations is presented. Using the results of the WDA from the previous presented, a situational instantiation of the work domain model was developed. The hypothetical situation has two available ambulances (one with a paramedic and one without) and two emergencies (one person having a heart attack and one person with a broken leg). How should the dispatcher allocate the ambulances to handle the emergencies? To assist in answering this question, the situation was mapped onto the work domain model (Figure 3).

The characteristics of the situation are shown together on the topographic map at the physical form level. The middle three levels are partitioned (i.e., by the dashed line) into the domains of potential risk and mitigation resources. The top level is the same for the two sections, because there is a common purpose of providing care for injured people based on acceptable risks and resource constraints.

In the domain of potential risk, the emergencies are identified at the physical form level (e.g., location and characteristics of the heart attack and broken leg victims). The physical function level maps the results of an analysis of the emergencies (e.g., chest pain and inability to walk). At the generalized function level, the urgency of these impairments is noted (e.g., high urgency for chest pain and low urgency for inability to walk). The abstract function level identifies the assessment of these emergencies based on the priority criteria of survival and damage to the injured. The functional purpose level identifies the acceptable risks and value judgements associated with handling the emergencies, while taking into account response resource constraints.

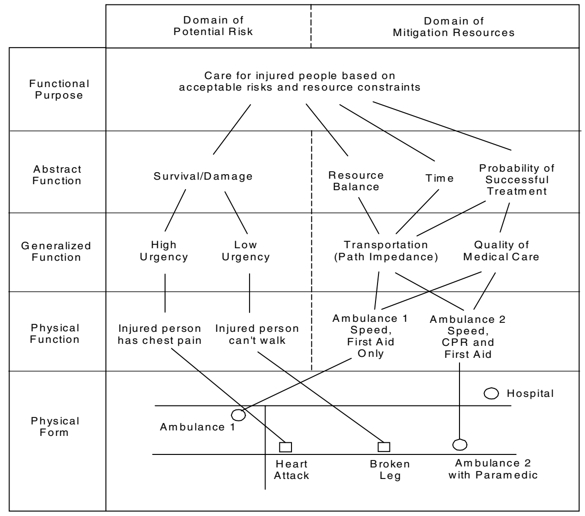

Figure 3: A situation mapped onto the work domain model for EADM.

The domain of mitigation resources manages the risk of the emergencies within the environment. At the physical form level, the response resources are identified (i.e., ambulance teams at locations with particular characteristics). The physical function level maps the functional capabilities of the two ambulances and personnel (e.g., ability for personnel to conduct first aid and cardiopulmonary resuscitation (CPR), and capabilities of ambulances in terms of speed). The generalized function level maps the general transportation and quality of care capabilities of the two ambulance teams. The abstract function level maps the time, resource balance, and probability of successful treatment in reference to the two ambulance teams. The functional purpose level is the same as is mentioned for the domain of potential risk.

An ambulance dispatcher may use the structure of the work domain model to assess emergency situations and allocate resources appropriately. In the situation described in this section, ambulance 1 is closer to the heart attack victim. However, the medical capabilities of ambulance 1 results in a lower chance of success in providing care for the heart attack victim, because they do not have the capabilities of providing CPR. On the other hand, if ambulance 2 (that has CPR capabilities) cannot arrive at this emergency in time, the heart attack victim may die. The dispatcher is able to reason through these conflicting factors (i.e., time to reach the heart attack victim and probability of successful treatment) using the abstraction hierarchy and make a judgement based on the priority criteria of survival and damage to the injured people.

WDA FOR MILITARY COMMAND AND CONTROL

The command and control system used to manage military actions within a theater of operation represents another example of an intentional system where WDA can be

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applied. In this section, we provide a preliminary analysis for military command and control (C2).

In general, C2 incorporates the management tasks of planning, coordinating, decision making, and controlling both forces (assets) and operations (objectives and plans). For large-scale, complex operations, C2 as an intentional system can be described at many different levels of granularity. For instance, a commander may be making management decisions about an entire air campaign that involves hundreds of airplanes and thousands of sorties spread over several days. At a different time the focus of a decision may be limited to the management of a single mission involving only a few assets. Many decisions also involve crisis management similar to the EADM work environment.

As we have indicated earlier, our general strategy for conducting a WDA is to first determine the characteristics of the work environment, and purpose and scope of analysis. For the purposes of this example, we briefly outline the sources for intentional and causal constraint for C2 at a military air operations center. The purpose of analysis is to provide decision support for the commander at the operations center. The scope of analysis includes aspects of an air interdiction, including geography, and the functional capabilities and limitations of friendly forces, equipment, and military threats. Then we instantiate the analysis for an event associated with an air interdiction mission by mapping the situation to the framework.

Air Interdiction is defined by Joint Pub 1-02: "Air operations conducted to destroy, neutralize, or delay the enemy's military potential before it can be brought to bear effectively against friendly forces…." Imagine that a strike package has been assembled to perform an air interdiction mission as part of the daily operations in a military campaign. Based on available information, it is believed that the enemy has active surface-to-air missile (SAM) sites in the targeted area. Because these pose a high threat to the strike package, a support element (Suppression of Enemy Air Defenses – SEAD) has also been included as part of the interdiction mission. SEAD support is provided by 4 F-16CJ, Block 50 airplanes. Twenty-five minutes before planned time-over target (TOT), however, the F-16 flight lead calls an air abort and returns to base. The Air Component Command in the Air Operations Center, who is managing all air campaign operations, is apprised of the situation. The commander must decide how to manage the new situation. One option may be to find out if other SEAD aircraft are available to handle this mission. Another option is to look for other types of assets. It may also be possible to adjust the TOT time. Other actions are also possible (e.g., request new intelligence to determine activity state of the SAMs). Further, mission abort is always an option. What action should the command take? What constraints shape the response?

The preliminary WDA for C2 proceeded by dividing the work environment into two "object worlds", in a similar fashion to that presented for EADM. The domain of military encounter includes the potential risks or threats associated with the functional capabilities, limitations, and consequences of the enemy forces and equipment. The domain of friendly assets includes the functional capabilities and limitations of military resources and assets to combat these risks.

Figure 4 summarizes a preliminary analysis of the military C2 problem in terms of intentional and causal constraints as they are reflected at each level of the abstraction hierarchy. The C2 work environment is established and activated in order to achieve a military course of action that is deemed to be in the best interest of the country by national command authority (i.e., functional purpose). The goals, guidance, policies, and practices used to accomplish the objectives of a course of action are some of the intentional factors that compress the domain of military encounter at the level of abstract function. In addition, priority measures may be imposed from such things as public opinion, congressional concerns, and the like. For example, injury to friendly forces or civilian casualties may serve as a cause to terminate military action before the objective is met. The command must balance these intentional issues. Similarly, time and resource issues, and probability of success over a campaign and within a mission must be balanced.

Level of Abstraction	Domain of Military Encounter	Domain of Friendly Resources
Functional Purpose	Goal: To accomplish a military course of action deemed to be in the best interest of the country by the national command authority	
Abstract Function	Priority criteria and given level of acceptable risk balance (e.g. public opinion, congressional support, international relations, rules and regulations)	Time, resource balance within engagement region, probability of successful engagement
Generalized Function	Urgency of military threats, situation assessment; information coordination; decision coordination and collaboration	Transportation, effectiveness of military resources for engagement
Physical Function	Functional capabilities and limitations of military threats, trust/belief in information, risk/outcome estimation and projection; information assurance	Combatant skills, functional capabilities and limitations of equipment and weapons
Physical Form	Location of military threats, Information location, method, and form of delivery; communication modes; collaboration modes	Location of people, equipment, weapons, geographic landscape, air space landscape, weather

Figure 4: Preliminary abstraction hierarchy for military C2.

At the generalized function level, intentional constraints derive from concerns about assessing the military situation or threat, acquiring and disseminating information, and coordinating diverse concerns among interrelated action organizations. The general transportation capabilities of the military resources and effectiveness of engagement over the duration of the campaign imposes causal constraints on action.

When considered at the physical function level, the functional capabilities and limitations of individual weapon systems and military staff available to use and maintain them form constraints on action in the domain of friendly resources. Constraints for the domain of military encounter include the functional capabilities and limitations of military threats and attitudes toward the available information in terms of trust, risk, and consequences.

Constraints at the physical form level of description are the geographical distribution of assets relative to the military objective for the domain of friendly resources. The characteristics of enemy threats, medium of expression for

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information, and accessibility, serve as constraints for the domain of military encounter.

The results of this preliminary WDA attempts to provide insight into the range over which an intelligent actor(s) can make adaptive adjustments to meet expected and unexpected situations on the way to achieving the objective. It directs the analyst's attention to the factors that shape the workspace by modeling the relevant constraints that co-exist in the work environment. Some appreciation for how the framework can guide effective analysis is seen by inspecting the illustration of the air interdiction mission that included an air abort of the assets assigned to suppress enemy defenses in the vicinity of the target. Figure 5 shows a mapping of the mission (only the SEAD support is emphasized) onto the analysis framework.

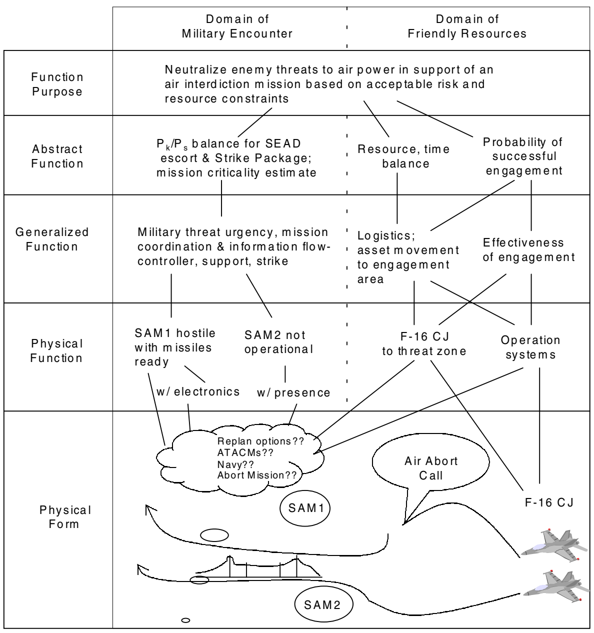

Figure 5: Mapping of threat suppression support (Air Interdiction Mission) to the work domain model.

When commander learns about the air mission, he must reason through the abstraction hierarchy to reframe the situation in terms of intentional and causal constraints. It is possible that very little time will be needed at some levels (i.e., they are stable and still apply with little or no modification). There is a limited amount of time in which to make a decision. Constraints will shape how this time is spent. For example, one possibility is to execute the mission without SEAD suppression. If there is some question about the state of the SAM site (i.e., there is some doubt that it is active today), the commander may wish to collect some new intelligence to reassess the site status. But, if there are no uninhabited aerial vehicles in the area and time is very limited, or the information channel is slow and can only provide low resolution information, then this option may not be seriously considered. This might be the commander's first option but constraints remove it from consideration. As a result the workspace is such that only alternate support options are considered, and if none can be found, a mission abort order is issued.

CONCLUDING REMARKS

The preliminary analyses presented for EADM and C2 demonstrate that WDA can be conducted for intentional systems. One lesson learned is that it is important to consider the characteristics of the work environment, and purposes and scope of analysis before one proceeds to conduct a WDA. Otherwise there is the danger of modeling the work environment with constraints that are inappropriate or incomplete based on the purposes and scope of analysis. The consideration of these factors may provide some insight into making the WDA approach less of an "art" and more replicable and reliable (i.e., robust) for the same work environment, purpose, and scope.

There are a number of directions that can be taken for future research. First, the preliminary WDAs can be further developed by gained deeper domain knowledge in the areas of EADM and C2. Second, once detailed WDAs have been conducted, they can specify the informational requirements (i.e., content and structure) for human-computer interface design. These requirements may be encoded in a graphical form that supports decision-making and accommodates the capabilities and limitations of the operators. Third, a number of work environments can be characterized as intentional systems, and may benefit from a WDA similar to the ones presented in this paper (e.g., medical and financial domains).

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