A Field Study of Emergency Ambulance Dispatching: Implications for Decision Support

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A FIELD STUDY OF EMERGENCY AMBULANCE DISPATCHING: IMPLICATIONS FOR DECISION SUPPORT

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To inform the design of computer-based support for decision making, a field study was conducted in a communication centre for emergency medical services (EMS). 142 hours of direct observations, spanning 13 different shifts were conducted. EMS is an intentional work domain that emphasizes human-human interaction over human-machine interaction. This study focused on the information requirements for EMS dispatching, the collaboration between EMS personnel within and beyond the communication centre, and the information that is currently available to the dispatchers. An abstraction-decomposition space (Rasmussen, 1985; Vicente, 1999) was used to model the information requirements in this work domain, and to identify opportunities for enhancing and/or redesigning the decision support.

INTRODUCTION

In the past, the cognitive engineering community has tended to study and design computer-based support for human-machine interaction in work domains that are primarily causal (i.e., governed by physical laws) rather than social (i.e., governed by human intentions) in nature. However, as the interest in intentional work domains grows (cf., Wong, Sallis, and O'Hare, 1998; Hajdukiewicz, Burns, Vicente, and Eggleston, 1999), it becomes increasingly important to understand the role of human-human interaction and how it can be enhanced by computer-based support. This study uses emergency ambulance dispatching as a natural laboratory for investigating computer-mediated human-human interaction in the context of an intentional work domain.

Similar to most other complex work domains, the emergency medical services (EMS) domain is characterized by risk, uncertainty, and highly dynamic behaviour. However, EMS also has a highly dynamic structure (i.e., the patients and ambulances that are in the system change from one minute to the next), and is highly distributed both physically (e.g., dispatchers in the communication centre collaborate with paramedics on the road) and functionally (e.g., dispatchers collaborate with call receivers within their organization, and with police, fire, hospitals outside their organization). Most importantly, unlike the human operators in many causal work domains, ambulance dispatchers work with loosely coupled objects (i.e., patients, ambulances and hospitals). They have no control over most objects in the work domain (i.e., patients and hospitals), and they have no direct control over any object, including ambulances, which are directly controlled by the paramedic crews.

In recent years, the demand for ambulance services has continued to rise in the province of Ontario in Canada (Ministry of Health and Long-Term Care, 2001), possibly due to a growing and aging population. At the same time, budgetary pressures have limited the availability and efficiency of services provided by hospital emergency rooms (ERs) (e.g., closings of some ERs, continuous overcrowding and understaffing in the ERs that remain open). Ongoing offload delays at the ERs limit ambulance availability, increase wait times for ambulances, and pose potential threats to patient safety (Hume, Cudmore, Hamilton, and Brean, 2001; Lakey, 2001). Therefore, there is tremendous pressure on ambulance dispatchers to make effective and efficient use of the ambulance resources at their disposal.

This field study identifies the information requirements for emergency ambulance dispatching and represents them in the form of an abstraction-decomposition space (ADS) (Rasmussen, 1985; Vicente, 1999). It also examines the distribution of responsibility between various stakeholders in the work domain, assesses information availability from the dispatcher's perspective, and identifies opportunities and challenges for the design of decision support.

METHOD

This field study was conducted at the Central Ambulance Communication Centre for the Metropolitan Toronto Emergency Medical Services in Toronto, Canada. This centre services an urban area that spans 580 km^2, and has a "daytime" population of 4 million (including commuters who travel into the city) and a "nighttime" population of 2.5 million. In one year, approximately 425 700 calls are processed, 265 000 responses are made by ambulances, and 179 600 patients are transported. The city is divided into 38 station areas distributed over four quadrants, and one dispatcher controls each quadrant. At peak times, each dispatcher is responsible for about 15 to 20 ambulances.

A total of 118 hours of direct observations were conducted in the centre, spanning eleven shifts that occurred during different days of the week and different times of the day. Ten key dispatchers, with experience ranging from 0.75 to 20 years, were observed for a minimum of four hours each. Twelve other dispatch personnel, including call receivers, hospital coordinators, and supervisors were also observed to obtain a complete picture of the ongoing collaboration among various stakeholders. In addition, 24 hours of direct observations, spanning two full shifts, were conducted of two different paramedic crews at different skill levels (i.e., Advanced Life Services and Basic Life Services).

In this study, data were collected on the physical layout of the communication centre, the various stakeholders who communicated in real-time, their physical and/or functional relations, and the means, frequency, and content of these communications. Data were also collected on the content, structure, and form of information used by the dispatchers, including information that is available in paper and electronic formats. Information requirements were then represented in the form of an ADS, to the extent possible, and presented to a small group of domain experts including: a medical director of pre-hospital care, a project manager in pre-hospital care / former paramedic, and a quality improvement coordinator for the communication centre. Based on their feedback, gaps in the ADS were filled and other refinements were made. The revised ADS was then re-presented to the above experts as well as to managers of the communication centre to inform further refinements.

RESULTS

Information Requirements

The abstraction-decomposition space (ADS) provided a useful framework for mapping out the information requirements for emergency ambulance dispatching. Within an ADS, the decomposition (i.e., part-whole) hierarchy is used to represent a work domain at different levels of resolution from coarsest (i.e., entire system) to finest (i.e., single components). In the case of emergency ambulance dispatching, five levels of decomposition were found to be useful (see Table 1): *Metro Area*, *Quadrants*, *Station Areas*, *Units*, and *Components*.

Metropolitan Area	Toronto (1 in total)
Quadrants	Northeast, Northwest, Southeast, Southwest (4 in total)
Station Areas	• #10, 11, ... (38 in total)
Units	• Ambulance Units (number varies depending on day and time, but usually 40 - 80 in total) • Emergency Response Units (number varies depending on day and time, but usually 1-6 in total) • Hospitals (22 in total) • Patients (number varies from minute to minute)
Components	• Trucks (1 for each ambulance unit, plus spares) • Jeeps (1 for each response unit, plus spares) • Paramedics (2 for each ambulance unit, 1 for each response unit, plus spares)

Table 1: ADS for Emergency Ambulance Dispatching – Part-Whole Hierarchy.

	Risks	Resources
Functional Purpose	Threat to Public Health *<% high-priority calls not given advanced care, % time with inadequate coverage, avg unit utilization>*	Public Health *<% high-priority calls given advanced care, % time with adequate coverage, avg unit utilization>*
Abstract Function	Death / Deterioration (of patient(s)) *<response times (rt); avg rt or % rt beyond targets>* Bottleneck (at hospital(s)) *< offload delay (od); avg od; % od beyond target>* Lack of Coverage (for station area(s)) *< area not covered by an advanced unit / by any unit; % areas not covered by an advanced unit / by any unit>*	Survival / Improvement (of patient(s)) *<response times (rt); avg rt or % rt within targets>* Turnaround (at hospital(s)) *< offload delay (od); avg od; % od within target>* Coverage (for station area(s)) *< area covered by an advanced unit / by any unit; % areas covered by an advanced unit / by any unit>*
Generalized Function	Response priority (of a patient) *<alpha (non-life-threatening) to echo (vital-signs-absent)>* Mobility (of a patient) *<ambulatory or immobile>* Triage priority (of a patient) *<levels 1 (most urgent) to 5 (least urgent)>*	Care (by an ambulance / response unit) *<primary or advanced>* Transport (by an ambulance / response unit) *<of ambulatory patient or of immobile patient>* Admittance (by a hospital) *<of pediatric patient, trauma patient, etc.>*
Physical Function	Injury/Disease (of a patient) *<e.g., cardiac, breathing problem, seizures, etc.>*	Skill (of an ambulance/response unit) *<basic or advanced>* Transfer Capacity (of an ambulance/response unit) *<with or without stretcher>* Treatment (by a hospital) *<e.g., general, pediatrics, or trauma, etc.>*
Physical Form	Patients *<location; id>*	Ambulance / Response Units *<location; id; status>* Hospitals *<location; id; status >*

Table 2: ADS for Emergency Ambulance Dispatching – Means-End Hierarchy.

The abstraction (means-end) hierarchy of an ADS is used to represent the relationships between the physical objects and the functional purposes of a work domain. Moving up the hierarchy identifies the ends (i.e., higher-level functions) that can be achieved by a current function, and moving down the hierarchy represents the structural means (i.e., lower-level functions or physical objects) that can be used to achieve the current function. In the case of emergency ambulance dispatching, five levels of abstraction were found to be useful (see Table 2).

The means-end links between functions at different levels of abstraction can be complex and diverse. For example, an ambulance unit with advanced skill (cf. physical function level) can be used as a means for both primary care and advanced care (cf., generalized function level) (i.e., a one-to-two relationship moving up the hierarchy); but an ambulance with basic skill can only be a means for primary care (i.e., a one-to-one relationship). Most hospitals (cf., physical form level) are means to many different treatments (cf., physical function level) (i.e., a one-to-many relationship moving up the hierarchy); the same treatment offered by different hospitals (cf., physical function level) are all means to the admittance of a patient needing that particular treatment (cf., generalized function level) (i.e., a many-to-one relationship moving further up the hierarchy).

There are also important dependencies between the "risks" and the "resources" in the EMS domain. For example, to find means for the survival/improvement of a given patient (i.e., moving downward from the abstract function level), it is necessary to examine the relationship between response priority and the care. Specifically, primary care is a means of survival for a patient at a low priority, but may not be a means of survival for a patient at a high priority.

There are conflicting constraints at every level of abstraction. For example, at the *abstract function* level, when an ambulance responds to a call -- thereby fulfilling the function of "survival/improvement"-- it stops fulfilling the function of "coverage". At the *generalized function* level, although a unit may be capable of both advanced and primary care, when it gives primary care to a low-priority patient, it becomes unavailable to give advanced care to a subsequent high-priority patient. Therefore, the dispatcher is constantly challenged to consider how the effects of his/her decisions will propagate through the work domain.

Distribution of Responsibility

Since the EMS domain is highly distributed, dispatchers are required to communicate constantly with many diverse stakeholders to gather the information that they need to make decisions. Understanding how authority and responsibility is distributed among the various stakeholders facilitates an understanding of who has access to what information, and what dependencies and redundancies exist for the exchange of information. The ADS, and in particular the part-whole hierarchy, was useful for contrasting different stakeholders' scopes of responsibility.

- whole vs. part (e.g., shift supervisor responsible for Metropolitan Area versus dispatcher responsible for one Quadrant; or dispatcher responsible for many ambulance units in the Quadrant versus paramedic crew responsible for a single ambulance Unit)
- part vs. part (e.g., dispatchers for different Quadrants); and
- different objects (e.g., hospital coordinator responsible for Hospitals versus Dispatcher responsible for ambulances).

Interestingly, it was sometimes useful to contrast the realms of the same two stakeholders in multiple ways (e.g., dispatcher responsible for ambulances versus paramedic crew responsible for the patient – they are responsible for different objects as well as for a whole versus a part).

Information Availability

Information that is directly available to a dispatcher places the lowest demands on his/her cognitive resources (i.e., attention and memory). Since the dispatcher already needs to divide attention over many ambulances, and different ambulances tend to be involved in mostly independent activities that are at different stages of completion, an analysis of what information is available (or unavailable) can be useful in identifying opportunities for offloading the dispatchers and enhancing the current computer-aided dispatch system. In this study, the information that was available to dispatchers was classified as:

1) automatically presented to the dispatcher (i.e., most available);
2) automatically presented or presented as a result of annotations by the dispatcher;
3) presented only as a result of annotations by the dispatcher;
4) presented as a result of annotations by the dispatcher or remembered by the dispatcher; or
5) only remembered by the dispatcher (i.e., least available).

Information that was available to the dispatcher was also analyzed in terms of source type (i.e., sensed versus reported) and source redundancy (i.e., reported by single-source-single-modality, sensed AND reported by single-source-single-modality, reported by single-source-multiple-modalities, or reported by multiple-sources-multiple modalities). The dispatcher has access to many kinds of information that vary along the type and redundancy dimensions. Therefore, it appears difficult for the dispatcher to assess, in real-time, the reliability of an information source and the means that are available for improving the reliability of a source. Since reliability of lower-order information has a direct impact on the reliability of higher-order information that can be derived, this analysis is essential for assessing the feasibility and potential utility of any decision aids that can be designed.

DISCUSSION

The field observations and ADS model presented above have helped us to identify some key opportunities for the design of computer-based support for emergency ambulance dispatching.

Providing High-Level Feedback

According to the ADS presented in this paper, a key function of EMS is patient survival and improvement (refer to abstract function level in Table 2). While the survival and improvement of a patient ultimately depends on many factors (e.g., his/her underlying condition, the treatment received at the hospital, etc.) that are beyond the control of EMS dispatchers, it is possible to develop and display heuristic measures of survival and health to aid dispatchers in making decisions, for example: the response time of the first ambulance to arrive on scene, or in life-threatening scenarios, the response time of the first *advanced* ambulance to arrive on scene. There are target response times for different types of patients, but neither these targets (08:59 for life-threatening cases and 19:59 for non-life-threatening cases) nor the performance of dispatchers relative to these targets are shown in the current computer-aided dispatch system. In other words, dispatchers currently receive little real-time guidance and feedback at this high level of abstraction.

Dispatchers also receive little guidance and feedback at high levels of aggregation (refer to metro and quadrant levels in Table 1). For example, as dispatchers consider response times across patients, should they try to minimize the average response time or maximize the percentage of response times within target? And does the correct way to aggregate response times across patients vary for different types of patients (e.g., average response times for severe patients, percentage within targets for less severe patients)? Unless the relationships between the performance of a single unit to the performance of a quadrant or even metropolitan area is made explicit to the dispatchers, it may be difficult for dispatchers to be aware of their own performance and to work towards consistently high levels of performance.

Displaying Coverage

A key function of EMS (see abstract function level in means-end hierarchy in Table 2) is to provide coverage of a geographic area with the available ambulances in anticipation of any emergency calls that may come in. While dispatchers currently have real-time information on the locations and status of individual ambulances in a map display, coverage is defined by the relationships (i.e., distances) between ambulances or between ambulances and important landmarks (e.g., areas of high call volume). There are also different levels of coverage (i.e., an area may have coverage by an advanced ambulance, or only by a basic ambulance). Therefore, one potential direction for the development of decision support is to provide explicit feedback on how thoroughly a dispatcher is covering his/her area (e.g., inter-ambulance distances, areas of little or no coverage). However, it is important to make coverage computations and displays context-sensitive with respect to the number of ambulances that are available at the time.

Showing Tradeoffs and Constraints

The survival of a patient depends on both his/her response priority (i.e., is the patient's life-threatened?) and the care provided by the ambulance unit (i.e., advanced or primary) (cf., relationship between abstract function level and generalized function level in the means-end hierarchy). The matching of response priority to form of care also needs to be weighed against response time (cf., abstract function level). While there are some commonly known and accepted heuristics (e.g., send the closest ambulance, or send an advanced crew to a high priority call), these can only be reliably applied in straightforward situations (e.g., closest ambulance is also the most appropriate in terms of the care). In more complex (but fairly common) situations (e.g., closest ambulance to high-priority call can only provide primary care, and the closest ambulance that can provide advanced care is quite far away), it is not always clear how to select between the available sub-optimal options. By making explicit the structural means-end relationships between: 1) different matches of ambulance units to response priorities (i.e., the generalized function level) and 2) target, estimated and actual response times (i.e., the abstract function level), the dispatchers may be able to make more informed and justifiable decisions in difficult situations.

CONCLUSIONS

The domain of emergency ambulance dispatching is dominated by single-sensor-single-indicator displays. The use of an ADS helped us to identify many examples of higher-level information that are currently unavailable to the dispatchers, but that can be derived from low-level data that are already being tracked and recorded by the computer-aided-dispatching (CAD) system (e.g., average response times derived from individual response times, inter-unit distance derived from individual unit locations). Moreover, for functions that are difficult or impossible to measure directly, using the ADS as a starting point for knowledge elicitation has enabled us to identify appropriate "heuristic" measures (e.g., response time as a heuristic measure of patient survival).

There is, however, a prevalence of reported rather than sensed low-level data in this work domain. If the process for inputting reported data demands too much time and attention and distracts the dispatcher from his/her primary task, the reported data may never be captured by the CAD system. Higher-level information that is derived from incomplete and/or unreliable low-level data will be inaccurate and misleading. Therefore, it may be worth exploring the use of emergent features to reveal the logic behind computations to support error-checking.

Finally, this study pointed to the potential benefits of presenting data in context (e.g., actual response times in the context of target response times, offload delay times in the context of target offload times, etc.).

By evaluating the impact of these recommended changes experimentally, we can gain a better understanding of intentional work domains and perhaps also design systems that are more robust to the stressors currently faced by EMS facilities, thereby contributing to both basic and applied research aims.

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REFERENCES

Hajdukiewicz, J. R., Burns, C. M., Vicente, K. J., and Eggleston, R. G. (1999). Work domain analysis for intentional systems. In Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting (pp. 333-337). Santa Monica, CA: HFES.

Ministry of health and Long-Term Care, Technical Services Unit. (2001). Service Call Volume Report: By Year/Overall Priority 1-4 and 8. Toronto, Ontario: Author.

Hume, M., Cudmore, J., Hamilton, G., and Brean, J. (2001, June 9). Paramedic services strained coast to coast. National Post, pp. B11.

Lakey, J. (2001, November 17). Ambulance waits increase: Number delayed an hour at hospital rise again. The Toronto Star, pp. B1, B3.

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decisionmaking and system management. IEEE Transactions on Systems, Man, and, Cybernetics, 15, 234-243.

Vicente, K. J. (1999). Cognitive work analysis: Toward safe, productive, and healthy computer-based work. Mahwah, NJ: Lawrence Erlbaum Associates.

Wong, W. B. L., Sallis, P., J., and O'Hare, D. (1998). The ecological approach to interface design: Applying the abstraction hierarchy to intentional domains. In Calder, P., and Thomas, B. (Eds.), Designing the Future: Proceedings of the Eighth Australian Conference on Computer-Human Interaction OzCHI'98 (pp.144-151). Adelaide, Australia: IEEE Computer Society Press.