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“Trustworthy, transparent, nongovernmental health care rankings are possible, but they must be conducted in a manner in which access to data, nonproprietary methods, and ease of replication are facilitated.”

—Consumer Rankings and Health Care:
Toward Validation and Transparency
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Field Notes

Using Human Factors Design Principles and Industrial Engineering Methods to Improve Accuracy and Speed of Drug Selection with Medication Trays

Field Notes provides a forum for brief reports on in-progress innovations in quality and patient safety. Readers are invited to send Field Notes proposals to Steven Berman at sberman@jcrinc.com.

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Driving Forces

In recent years, health care has taken a significant interest in system design and interface usability. According to the Institute of Medicine,¹ at least 44,000 people die from medical errors each year. Many studies illustrate how patient harm might be reduced by providing health care personnel with well-designed equipment²⁻⁴ and applying human factors principles, a field dedicated to the design of systems to facilitate intuitive human interaction.⁵

Emergency situations, specifically those related to deployment of a crash cart, require a diverse team to work together in unfamiliar situations. In these circumstances, medical personnel might be unfamiliar with the emergency equipment, possibly threatening the timeliness of the selection of necessary items.⁶ In the stress of an emergency situation, the user-intuitive nature of equipment is likely to be particularly critical. The application of human factors, including usability testing, can reduce user error through intuitive design of code carts and their associated medication drawers.^{5,7}

Medication selection in an emergency situation provides the opportunity to leverage systems efficiency methodologies and intuitive design principles to great effect.⁵ The preparation and management of code cart medications and supplies are complex and frequently result in shortages (for example, epinephrine-refilled syringes⁸) and subsequent back-order issues. Given current market conditions, a medication could be inconsistently available in the desired form (for example, syringe versus vials) or dosages, creating the need for flexible storage solutions at the point of patient care. At the hospital at which this study was conducted, customized medication trays were used to hold specific forms and sizes of products, limiting the flexibility of this hospital to respond to changing market availability.

Duration of initiative: Senior design project carried out during Winter semester, January–May 2012.

Setting: Veterans Affairs Ann Arbor Healthcare System

Whom This Should Concern: Performance/process improvement personnel, nurses, pharmacy technicians, patient safety professionals and researchers.

Initiative Description

To respond to the issues previously outlined, in January 2012, pharmacy leadership at a US Department of Veterans Affairs (VA) hospital enlisted a Capstone student team of four industrial engineering students [including D.C.] from a local university. The team was supported by a supervisor [V.J.C.], an official project owner [M.E.B.], and a secondary project owner [A.Z.A.]. Specifications for this hospital include the following:

- Bed count: 154 total (114 acute, 40 subacute)
- Code blue occurrences: rare (< 5 per month, on average)
- Level 1B Tertiary Referral Facility
- Diverse range of complex surgical and medical services
- Inpatient mental health services
- Comprehensive interventional cardiology and radiology services
- On-site hemodialysis and infusion services

The team set out to (1) analyze and document the problems with the current medication trays, some of which hospital personnel had identified as persisting issues, and (2) develop a prototype medication tray to address those problems, including speed and accuracy of medication selection.

The project began with a search of health care literature of studies on various code cart features.^{5,7,9} A search of human factors engineering (HFE) and design literature was used to

identify commonly used methods for analyzing design reliability and intuitiveness.¹⁰ The work in this project was strongly influenced by the approach described by Rousek and Hallbeck⁵ and McLaughlin.⁷ The team structured the analysis, prototype development, and testing in the following five-step process:

1. End user surveys to assess current tray design
2. Usability tests in simulated mock codes to test the usability, accuracy, and timeliness of medication selection from current-design trays
3. Problem identification from Steps 1 and 2 to iteratively develop prototype tray design(s)
4. Usability tests in simulated mock codes to test the usability, accuracy, and timeliness of medication selection from prototype trays
5. Surveys to assess end users' reactions to prototype tray design

This project is unique in that information revealed during the usability tests with the current trays was used to inform the development of the prototype trays, which were then used in the second round of usability tests (as opposed to Rousek and Hallbeck,⁵ who created both tray design alternatives before conducting usability tests). That is, the prototype trays in this study were designed in response to observed issues in speed and accuracy of medicine retrieval, and end users were involved early on and continuously throughout the process, which allowed their needs to be met more easily and increased the chances that they would embrace the resulting prototype. We now describe each of the five steps.

This study was considered a quality improvement project and was therefore exempt from Institutional Review Board review.

TRAY DESIGN ANALYSIS, PROTOTYPE DEVELOPMENT, AND TESTING

Step 1. End User Surveys. The surveys were administered to 20 nurses and 6 pharmacy technicians to gather information on the following:

- Nurses' and pharmacy technicians' experience levels
- Strengths and weaknesses of current tray design
- Suggestions for improvement
- Common emergency situations
- Perceived error rates in medication selection or tray restocking

Step 2. Usability Tests—Current-Design Trays. The following HFE principles and industrial engineering methods were used to assess user interactions with the trays with 8 of the 20 nurses who participated:

- Decreased information access costs

Nurse Using Current Medication Tray Design in a Code Simulation



Figure 1. The photo shows a nurse performing one of the usability tests, which involved her using the current medication tray design in a code simulation (also available in color in online article).

- Maximum flexibility of tray usage
- Mistake-proofing, or “lock-out”
- Search theory
- Redundancy gain

A nurse manager [A.Z.A.] selected the 8 nurses as a representative cohort with differing levels of experience (that is, many years' experience in ICU nursing, moderate number of years in nursing, and relatively new to nursing). The nurses were tested on speed and accuracy of medication selection in four different simulations of emergency codes in accordance with current advanced cardiovascular life support (ACLS) guidelines for cardiopulmonary resuscitation and emergency cardiovascular care¹¹:

1. Selection of 5 medications in *random* order, with all medications placed in the *correct* tray slots
2. Selection of 5 medications in *random* order, with 2 medications *misplaced* (that is, in incorrect tray slots)
3. Selection of 10 medications related to standard *cardiac arrest* procedures, with all medications in the *correct* tray slots
4. Selection of 10 medications related to standard *cardiac arrest* procedures, with 2 medications *misplaced*

Each usability test was timed and videotaped. Figure 1 (above) shows a nurse performing one of these usability tests.

Step 3. Problem Identification—Prototype Tray Development. Current tray surveys and usability tests (Steps 1 and 2) helped the team identify specific problems to focus on for improvement. The prototype trays were developed in partnership with a local health care device manufacturer.

Step 4. Usability Tests—Prototype Tray Design. About a month after the tests with the current trays—to allow for the

Labeled Problem Areas in Current Medication Trays



Figure 2. Problems A–E are identified by location in the current medication trays (also available in color in online article).

Labeled Solution Areas in Prototype Medication Trays



- A. Spice rack vial slots
 - B. Flexible vial slots
 - C. Asymmetric tray sizes (5S control error-proofing)
 - D. Medicines placement order (frequency of use principle)
 - E. Left-side tray compartmentalization (grouping principle)
- Ergonomic and Lean principles applied:
- Reduce “waste of correction”
 - 5S “sorting” and “setting”

Figure 3. Solutions A–E are identified by location in the prototype medication trays (also available in color in online article).

time needed for the manufacturer to produce the prototype trays—the trays were evaluated using the same usability-test procedure used for the current trays and involved the same 8 nurses.

Step 5. Surveys—Prototype Tray Design. Following the prototype-tray usability tests (Step 4), the 8 nurses completed another round of surveys.

CURRENT TRAY DESIGN PROBLEMS AND PROPOSED SOLUTIONS

The current and prototype medication trays are shown in Figure 2 and Figure 3 (above), respectively, with the problems and corresponding solutions, which we now describe.

Hidden Vial Labels (Problem A)

Problem: In the current trays, vials were placed inside cylindrical slots that covered the entire manufacturer-applied medication label. In response, auxiliary labels were placed on the trays to indicate the contents of the stored vial. With only the vial caps exposed and auxiliary labeling to identify the vial contents, this setup was an “accident waiting to happen,” according to staff surveys. As a result, clinicians often defaulted to reading the auxiliary labels, instead of the actual vial labels, when selecting medications (suboptimal in the event of a misplaced medication). Clinicians who insist (correctly) on reading the vial labels are forced to check the auxiliary labels before reading the vial labels, representing an extra step that increases the information access cost of the vials’ contents. The extra time and movement

to read the vial label and the auxiliary label would likely decrease staff willingness to actually read the vial labels and potentially lead to overconfidence in performance.¹²

Solution: The “spice rack” design eliminates the preformed slots and auxiliary labels, instead using angular vial holders that are open and accessible. Without auxiliary labels, staff members responding to a code are forced to read the manufacturers’ vial labels directly to identify its contents. In addition, the spice rack design enables users responsible for restocking the trays to immediately recognize medications close to their expiration date.

Rigid Medication Slots (Problem B)

Problem: The cylindrical slots for medication vials in the current design are rigid and offer little flexibility in rearranging the vials to adapt to changes in available manufacturer packaging.

Solution: The vial holders in the spice racks are equipped with foam inserts that allow the flexibility to accommodate many shapes and sizes of vials. With these inserts, the arrangement of the vials can be customized to meet the changing needs of vial storage.

Similarity in Tray Sizes (Problem C)

Problem: As shown in Figure 2, the medication drawer is composed of two trays for a complete set of medications: one tray for syringes, and a second for vials. The trays in the current design are similar in size, allowing the possibility for duplicate trays to be stocked together.

Solution: Asymmetric trays decrease the possibility of erroneously

stocking two identical trays in the code cart drawer; stocking two vial trays in the code cart drawer would leave a noticeable gap in the drawer, whereas stocking two boxed syringe trays would be physically impossible, as each tray alone would require more than half of the drawer space.

This industrial engineering principle applied in this aspect of the design to physically prevent the stocking of two syringe trays is known as “mistake proofing,” which can reduce the likelihood of error.¹³

Nonintuitive Placement of Medications (Problem D)

Problem: Medications in the current trays are not arranged intuitively, which delays medication selection times.

Solution: People commonly search from left to right and top to bottom in an F-shaped pattern.¹⁴

According to interface design principles and search theory, for maximum visibility of high-usage medications, they should be arranged in the top-left corner of each tray.

Inconsistent Syringe Locations (Problem E)

Problem: The boxes containing the syringes are not stationary within the tray, leading to the possibility of the boxes being jostled during movement of the code cart. If the placement of the syringes is inconsistent because of jostling, then staff would require more time to search for any given syringe.

Solution: The syringes should be arranged in accordance with search theory, with the commonly used syringes placed in the top-left corner of the tray. To hold the syringes in those positions, barriers compartmentalize the tray so the boxes remain stationary when the code cart is in motion. Although the syringe boxes are coded by color to facilitate the search process, further differentiation will provide “redundancy gain” to accelerate medication selection by enabling users to search via various stimulus forms.¹⁵ Much like in the design of a traffic light (drivers can decipher the command on the basis of either color or position), users can search for syringes on the basis of box colors or positions in the tray.

Addressing Barriers

The team addressed possible barriers in carrying out the study. First, in the interest of a relatively large sample size and diverse perspective on problems with the trays, nurses with direct involvement in emergency codes and staff responsible for restocking trays (pharmacy technicians) were surveyed. Second, to help ensure the robustness of the design recommendations, both the current and prototype trays were evaluated by new, as well as experienced users. Finally, to minimize potential delays by the health care device manufacturer, a representative was aware of the project’s time line and was present for many of the

Table 1. Percentage of Vial/Box Labels Read by User Depending on Tray Design

	Current Design (%)	Prototype Design (%)	% Change from Current to Prototype
Vial	35	97.5	+178.6
Box	95	100.0	+5.3
Combined	75	99.2	+32.3

project’s important milestones, such as the usability tests.

Metrics

The key dependent variables analyzed during the project were completion speed of medication selection task, accuracy of medication selection during tasks, qualitative observations from the mock code videos, and subjective preference data from the surveys.

Results

User interactions in the usability tests, which involved 40 vials and 80 syringe boxes, were analyzed for each tray design. The 8 participating nurses were able to select the medications associated with standard cardiac arrest procedures and generally complete the procedure more quickly when using the prototype trays. When the medications were initially placed in their correct slots at the start of the trial, the completion time (mean [M] = 39.25 seconds) was lower for the prototype trays than for the current trays (M = 57.13 seconds), although not at a statistically significant level ($p = 0.08$; t -test). Similarly, when two medications were deliberately placed in incorrect slots at the start of the trial, the completion time was again lower for the prototype trays (32.88 seconds versus 42.75 seconds), but not at a significant level ($p < .012$).

When the nurses were tested with trays that contained the two deliberately misplaced medications, they were more prone to select incorrect medications when using the current tray design. When using the prototype trays, one mistake was made; with the current trays, seven mistakes were made (sometimes, multiple times by the same nurse).

Video analysis revealed that vial labels were much more likely to be read when the medication vials were displayed in the prototype (spice rack) design layout than in the current trays (Table 1, above).

Key Learnings

Several lessons can be gained from this experience in applying HFE principles and industrial engineering methods in the improvement of medication tray design. First, the spice rack

design might be an effective mechanism in decreasing the information access cost of reading vial labels (to the extent that any wasted label-reading time would be a valid proxy for access cost). With this design, staff were not required to read two labels (auxiliary and vial) to retrieve all relevant information and were less likely to make errors in the event of incorrectly stocked medications. As a result, they were faster and more accurate in medication selection tasks than when using the current medication trays. Second, the concept of allowing users to directly read manufacturer-affixed labels can be applied to other areas of health care, such as medication storage, intubation trays, anesthesia carts, and automated dispensing storage. More broadly, using HFE principles and industrial engineering to streamline or standardize work flows can represent a paradigm shift in the way that process improvement can be systematically initiated and implemented in the health care system.

As expected, the early and continuous involvement of end users, as we have described, helped us account for their needs in the design process, increasing the chances that they would embrace the new designs (as demonstrated by the subjective preference data), ultimately resulting in better performance.¹⁶ This engagement-fostering approach, in which those staff members' ideas and feedback were integrated into the prototype design, contributed to their enthusiasm for and intrinsic ownership in the changes.

What's Next

Since the project's conclusion in May 2012, the spice rack design for vial storage ("vial gripper") went on to be patented by the manufacturer, with publication in early 2015,¹⁷ and is offered for sale; we know of one hospital that is using this tray design. In summer 2015 the prototype tray design was further refined by a group of VALOR (VA Learning Opportunities Residency) pharmacy interns, who conducted further user testing regarding the exact placements of the vial holders within the larger tray layout and the arrangement of syringes for timely retrieval. Pilot testing in various code circumstances, particularly high-frequency code areas (acute units, ICU, rehabilitation unit) in the hospital was recently conducted, with results pending. **J**

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