Chapter 8

Systems Factors Influencing Decisionmaking

When decisionmaking is considered in the context of a work environment, many factors influence decisionmaking performance. Among these are the factors that are inherent in the work environment. We examined two: (1) workplace layout and (2) auditory alarms.

8.1 Workplace Layout

8.1.1 Introduction

The Trauma Resuscitation Unit (TRU) in a shock trauma center is the first place that the center's staff encounters critically ill patients. In this area patients are resuscitated, stabilized and evaluated for further treatment, surgery or release. The TRU bay is relatively small and there is a wide variety of medical instruments needed for the various tasks performed in the bay. The layout of items in the TRU bay can either help or hinder the working efficiency of the TRU staff. In emergency situations, placement of items used in critical tasks can greatly affect the speed of performance of these tasks.

Placement of items within a workspace is a compromise between human factors, the task to be performed in the workspace, and the physical constraints of the environment. An obvious goal in placement of objects in the workspace is to find a location that would serve all these factors equally well. This optimum layout would maximize the human's strengths while minimizing their limitations. An optimum layout would place all the tools required by the task where the user needs them, but not where they would get in the way when they are not needed. The workplace would be large enough to prevent clutter, but small enough to be comfortable. And best of all, gravity's limitation need not apply. This however, is rarely possible.

In order to balance these often opposing goals, principles of layout have been developed. Sanders and McCormick (1987, Ch. 13) suggest four principles of workspace layout (Importance, Frequency of Use, Functional, and Sequence of Use Principles; see Table 8.1) that guide the placements of items according to the task for which the workspace is intended.

Sanders and McCormick (1987)suggest a number of measures that are necessary for the evaluation of item placement in a workspace. Observing task performance in the workspace is critical to this evaluation, and both the frequency and importance of each item's use should be noted. With this information, the relationships between items, called links, can be examined. Information such as whether Item A is used before or after Item B are valuable in gauging the workplace's adherence to various principles of layout.

Previously, a few methods for evaluating this data have been suggested. Huebner and Ryack (described in Sanders & McCormick, 1987) used linear programming to find the arrangement of eight gauges that lead to an optimal combination of speed, frequency and accuracy. Any layout could be described as a deviation from this optimum layout. Bonney and Williams (1977) developed a computer program called CAPABLE that combines frequency of use and importance information data in order to find a layout that maximizes adherence to the four principles of layout. Layout Appropriateness is a usability inspection method developed by Sears (1993) to measure the efficiency of widget placement in computer interfaces. In Layout Appropriateness, the most efficient interface is the one requiring the shortest movement to perform common tasks. Layout Appropriateness measures the deviation from the optimal placement of computer interface objects.

The methods proposed by Huebner & Ryack, Bonney & Williams, and Sears share a weakness that prevents their use in a complex workspace like the TRU bay. These methods rely on the identification of an optimal, or near optimal, layout against which all options are measured. In workspaces with few items the optimal layout may be possible to identify. The linear programming example in Huebner & Ryack deals with eight items that can be arranged in eight factorial (or 40,320) possible combinations. In complex workspaces like the TRU bay, 40 items may need to be located in a small area for use by an anesthesiologist for a single task. That could lead to 40 factorial possible layouts that must be examined to locate an optimal layout! Because of the complexity involved in many tasks, layout appropriateness restricts itself to the placement of a small number of items in simple environments. CAPABLE on the other hand, employs a rule based heuristic to find a possible optimal layout without testing all layouts. Even with this approximating method, evaluation of complex workspaces remains a difficult, if not impossible, task.

Technical difficulties aside, methods that seek to establish an optimal layout are suited to the creation of new workspaces rather than the improvement of current workspaces. There are many situations in which the current layout already addresses many problems, and an incremental improvement is needed to either allow a new task to be performed in the area, or to modify the layout to improve performance in a very important task. A measure that allows comparison to the current layout, avoiding the complexity of optimum seeking methods, is preferable.

One method that is not based on an optimized solution was proposed by Banks and Boon (1981). Their Index of Accessibility combines frequency of use, the operator's reach, and distance of an item from the operator to assign a score to any layout. This method is far less complex than the methods previously mentioned, but it fails to address the sequence of use principle that Fowler's (described in Sanders & McCormick, 1987) data shows to be most important. A method based on links is required to measure this principle.

Workspace Appropriateness (WA) is a form of link analysis that is fine grained as well as quantitative that measures the relationship between the distance separating linked items and their importance. In this section we attempt to:

- Describe an adjustment to the layout of the TRU bay;
- Show how WA is used to gauge the impact of this design decision on the performance of a crucial task, tracheal Intubation; and
- Verify that the layout changes to the TRU bay have improved satisfaction with the bay without adversely affecting it's usability for a vital task, airway management.

8.1.2 Experiment 1: Initial Design

Method

Subjects Nine Anesthesia Care Providers (ACPs), nine nurses, and 17 surgeons who work regularly in the TRU bay were surveyed about their experiences in the TRU bays. Four of the ACPs and an additional seven nurses volunteered to participate in the critique of a new bay design.

Materials and Procedures Based on interviews conducted with representatives from each division, an open ended questionnaire was developed and distributed widely to the TRU Staff. The questionnaire asked: 1.) If there are particular pieces of equipment that interfere with the performance of their job, 2.) If there are particular items that they would like faster access to, 3.) If they can recall specific instances where vital information was not available to them, and 4.) If there are specific pieces of equipment that are not reliable.

Performance in the TRU bays was also observed directly and indirectly using videotapes of cases in the TRU bay.

Results

Comments from all subjects suggested that three problems most affect patient care:

- A barrier of tubes and wires limit access to parts of the bay and the patient. Lines radiate out from the patient at all angles, increasing the chances of accidental disconnects.
- The ACPs have difficulty seeing vital signs monitors and ventilator settings while engaged in patient care. These items are either mounted behind their heads or in front of them pointed in the wrong direction.
- Crowding is a serious problem for the staff. Up to 23 people can be found in a four by five meter space. This does not include equipment, supplies, or the patient. Lack of mobility only exacerbated this problem.

Figure 8.1 shows the current layout of the TRU bay while Figure 8.2 shows the new layout of equipment in the TRU bay devised to address these problems. The ventilator was moved to a position at the ACP's right where it can be viewed along with the vital signs monitor. This position allows the various tubes and wires to be concentrated into a single location that leave the rest of the bay open to staff movement. In addition, this layout is consistent with the operating room's ventilator placement.

Importance Principle	The degree to which the item is vital to the achievement of the task. Important items should be placed more conveniently.
Frequency-of-Use Principle	The frequency with which each component is used. Location should be a function of frequency of use. An arrangement should provide for the grouping of
Functional Principle	components according to their function. Items used for the same task should be located together.
Sequence-of-Use Principle	Patterns of relationships between items occur while performing tasks. Items should be arranged to take advantage of these patterns.

Table 8.1: Principles of Layout (Sanders & McCormick, 1987)

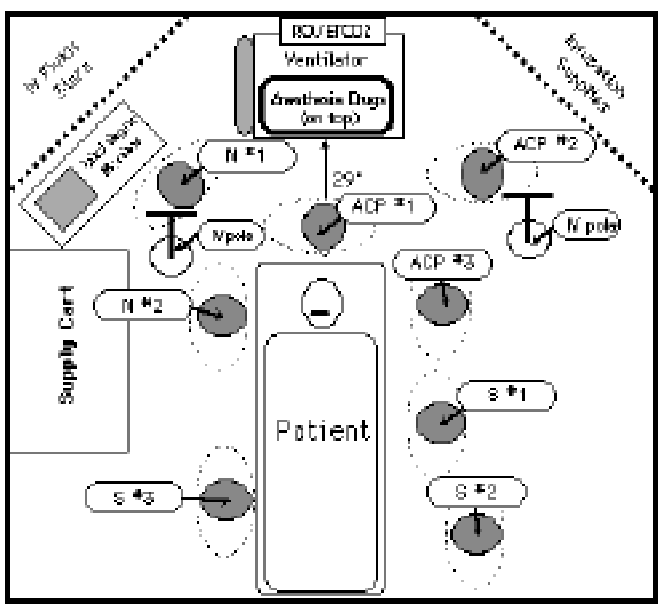

Figure 8.1: The current TRU bay layout with a standard compliment of staff. The ventilator placement in this layout requires the ACP to reach behind their back for equipment and information needed in airway management.

8.1.3 Experiment 2: Layout Efficiency

Method

Subjects Stationary video cameras positioned in two bays of the TRU (Mackenzie *et al.*, 1995) recorded the actions of ACPs performing airway management for nine trauma cases. An additional four ACP subject matter experts judged the importance of each item used for the task of tracheal intubation.

Materials and procedures Link Recording: Links were collected by coding the primary ACP's interactions using a computer coding system and tapes of nine cases of tracheal intubation in the TRU bay.

Item Importance Questionnaire : Item importance questionnaires were completed by four subject matter experts who were faculty anesthesiologists. These experts rated the anesthesia equipment in the TRU bay with regards to their ability to perform a resuscitation in the absence of various pieces of equipment. The questions incorporated a 10 point scale anchored at both end points and a middle score. For example, the question pertaining to the laryngoscope was anchored at its high point by the phrase ”vital in every case”, in its middle by ”vital in some cases”, and at its low point by ”useful but not vital”. Link importance was defined as the mean of the importance scores for the two items in the link.

Each item used, its location, the hand used, and the duration of use was recorded. These events were grouped into links between items. A total of 566 links were recorded. The location of each item in the link was coded, and the distance between these locations was measured in the TRU bay. Distance between items that are mobile were recorded the center of their total range of movement. Some links were between items at a specific location or repeated contact with a single item and were coded as having zero length. Links between the ACP's hands indicating items being shifted from hand to hand were not considered. Another set of links, items that were handed to the ACP, also were not considered because their distance could not be measured accurately. Link distances recorded in any of the observed bays were general to all bays because they are of identical size, and equipment placement is standardized.

The link importance and distance scores for the collected links were used to create a WA score for the current bay. The WA score is a measure of relationship between link importance, measured with the item importance questionnaire, and the link distance. Statistical measures of relationship generally measure deviations from a linear model of perfect relatedness. WA measured in real environments lead to maximum scores, with regard to inter-item distances, that fall substantially below the unconstrained perfect score of a linear model measure.

Using a simple correlation as a measure of relatedness in an unconstrained environment would yield WA values between +1 and -1. A WA score of -1 would indicate an ideal setup where links with the highest importance rating have short link distances. In a real environment though, ideal layouts will yield ideal WA scores that are significantly lower than the available maximum. For this reason the total range of WA scores is constrained and dependent on the individual workspace. It is inadvisable to draw conclusions about the magnitude of WA scores across workspaces. Directional conclusions (this layout is better/worse than the current layout) can be drawn when several scores are calculated for the same workspace. Magnitude judgments can be made when more than two options are considered (Option A is twice as efficient as Option B when compared to the current layout.)

Results

The observation of nine cases yielded 566 links between 25 items. The frequency of each link varied between 1 and 13 occurrences. Link importance scores ranged from 2.2 to 9.0 with a mean score of 7.4 and standard deviation of 1.1. The agreement between the four raters using the Kendall Rank Correlation ranged from 0.29 to 0.53 with each agreement significant ($p < 0.05$). Link distances ranged from zero to 230 cm. The correlation between link importance ratings and link distances for the current bay was -0.025. By substituting new link distances that reflect the updated bay layout in place of the current link distances but holding link frequency and importance constant we can predict efficiency of performance in the updated bay. The updated bay received a more favorable workplace appropriateness score of - 0.107. This difference supports the hypothesis that the TRU bay redesign will improve efficiency for the task of airway management.

8.1.4 Experiment 3: Satisfaction Measure

Method

Subjects: Nine ACPs, nine nurses, and 17 surgeons completed a subjective satisfaction questionnaire measuring satisfaction with the current bay layout. An additional 14 ACPs completed a satisfaction questionnaire after working in the revised bay layout.

Materials and procedures Subjective satisfaction questionnaire. The subjective satisfaction questionnaire consisted of 17 ratings scales and six directed comment areas rating the current resuscitation bay (see Figure 8.3). A questionnaire containing 13 of the original questions and another five questions measuring the ease of access to particular pieces of equipment was used to measure satisfaction with the subsequent bay layouts (see Figure 8.3).

Subjective satisfaction questionnaires were then distributed to 35 nurses, surgeons and ACPs working in the TRU bays. The updated layout was implemented in a single TRU bay where 14 ACPs completed the subjective satisfaction questionnaire after performing emergency intubation in the bay. These scores were compared to the satisfaction scores of the current bay layout.

Results

The mean satisfaction scores for all groups fell below the goal level of 7.0 on a scale of one to nine (See Table 8.2) with the ACPs expressing the lowest satisfaction. Although the ACPs were generally less satisfied than the rest of this sample, both nurses and

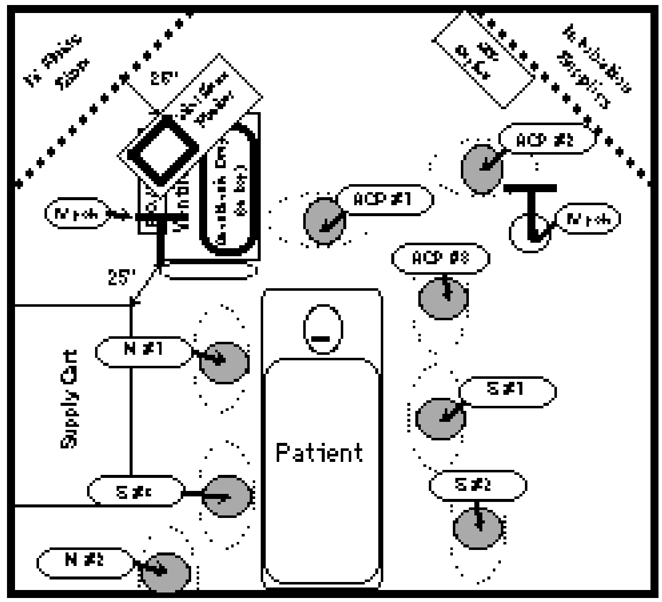

Figure 8.2: The updated TRU bay layout moves the ventilator and monitors into the work area while concentrating tubes and wires into a corridor between the ventilator and patient.

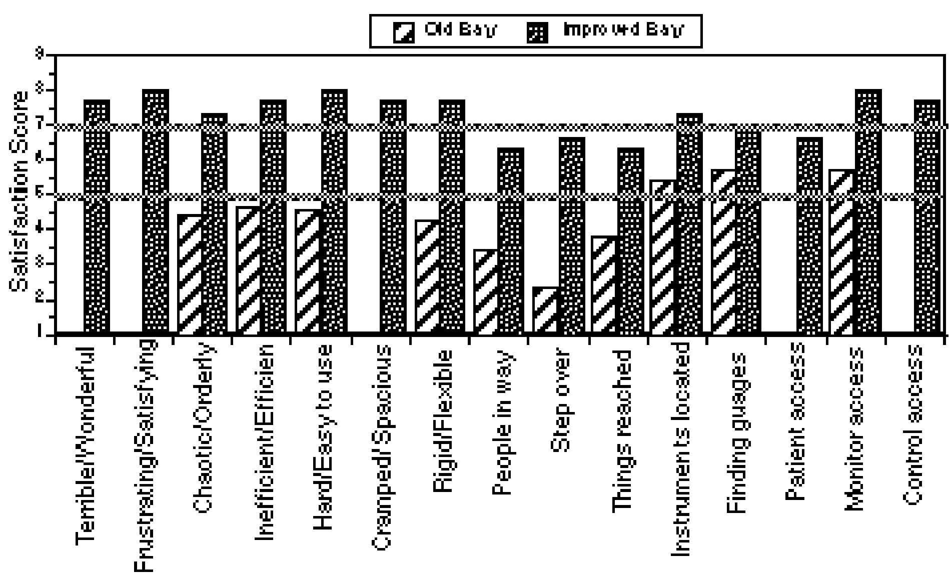

Figure 8.3: Comparison of subjective satisfaction scores before and after update. The older bay setup generally scored below the minimum satisfaction rating if five, while the improved bay layout surpassed this level and often rose above the goal level of seven.

Four Worst Ratings		Four Best Ratings	
You have to setup over wires and tubes	2.3	The vital signs monitor reliability	7.6
People are in your way	3.4	Equipment is reliable	7.4
Things that you need can be reached	3.8	Requests made to you are clear	6.7
General (Rigid or Flexible)	4.2	General (Equipment level)	6.7
People are in your way	3.7	The vital signs monitor reliability	7.8
You have to step over wires and tubes	4.6	Equipment is reliable	7.2
Members of the team work together	5.4	General (Equipment level)	6.7
General (Rigid or Flexible)	5.6	Instruments can be located	7.0
You have to step over wires ant tubes	4.2	Bays are prepared for your use	8.3
People are in your way	4.7	The vital signs monitor reliability	7.9
General (rigid or Flexible)	4.7	Equipment is reliable	7.7
Finding patient information	5.8	Requests to you are clear	7.7

Table 8.2: The four best and worst rated areas of the TRU bay divided by specialty. A number of the questions (7, 8 and 5) are consistently rated as poor by nurses, surgeons, and ACPs. Other areas, primarily related to the reliability and functionality of the equipment in the bay, were rated consistently high. ACPs Mean = 5.1 out of 9.0. Nurses Mean = 6.2 out of 9.0. Surgeons Mean = 6.9 out of 9.0.

surgeons had areas of active dissatisfaction. Specifically, limits to mobility, both human and equipment, cause the greatest dissatisfaction in the TRU.

Two questions that measure equipment accessibility and patient access were used to compare the usability of these aspects of the bay layout with the current bay and the updated version. The question that asked about the need to reach over tubes and wires showed a significant increase in satisfaction with the updated layout using the Mann-Whitney U (mean rank(current bay)= 8.2, mean rank(updated bay)= 14.4. U=29.0; $p < 0.05$). Similarly, the question asking about the need to step over tubes and wires produced a significantly higher score in the updated bay (mean rank(current bay)= 7.4, mean rank(updated bay)= 15.0. U=21.5; $p < 0.05$). This result suggests that the mobility problems of the current bay were effectively addressed without, as the WA score suggests, harming other areas of usability.

8.1.5 Discussion

”Probably the most common method of arranging components by using link data is through trial and error.” -Sanders and McCormick (1987)

The goal of this evaluation tool is to predict whether a new design would be better, the same, or worse than the current design. This type of information is useful in making incremental improvements in a workspace that, due to human and environmental constraints, is far from optimal with regards to the four layout principles. The TRU bay suffers a number of constraints (small bays, bulky equipment, and rigid placement of some vital equipment) that allow for only incremental changes to bay layout. WA predicted that our improved TRU bay layout improves efficiency for the anesthesia workspace (see Figure 8.4). The agreement between user satisfaction measures, usability experts judgments, and WA scores suggests that WA is an effective measure of one facet of usability. The predictive and linear response of WA suggests that this measure has construct validity.

A number of other link analysis methods have been used in the evaluation of medical environments. Some studies coded only the movement of the resuscitation staff within the room, allowing the detection of general (both tactile and visual) interactions of the medical staff with equipment (Smith *et al.*, 1993). This approach is difficult to apply to the Anesthesia Care Provider's domain in the TRU. Unlike the environment studied by Smith, et al., the TRU bay is too small to allow the ACP to move freely in the workspace. Subsequently, items used in resuscitation by the ACP are located within a close radius of the head of the bed. A measure of general movements of the ACP fails to identify actions during intubation when the ACP is primarily stationary. Other approaches using eye tracking (Boquet *et al.*, 1980) or time-lapse photography (Kennedy *et al.*, 1976) have been used but yield similar coarse grained results. These methods, although useful for basic research, are not directly applicable for ergonomic evaluation.

A qualitative view of the link analysis data gave an interesting look at the behaviors that the TRU staff developed to deal with usability problems. Because most of the equipment used in intubation is not within quick reach of the ACP, an assistant placed the equipment most likely to be needed around the patient's head and chest, and the primary ACP would take items from this cache of supplies. This crutch for a major ergonomic problem caused its own problems. First, the patient is an unstable platform upon which to place small objects. Secondly, this method requires the presence of yet another person in an already crowded bay. Finally, the placement of items on and around the patient is not at all consistent. This leads to the ACP searching for equipment during a time-critical procedure. This compensatory behavior is important to note because it suggests that we are measuring some abstraction of the TRU bay layout and that the actual bay, without these strategies, would score much worse.

Finally, WA serves a predictive role in workspace evaluation, predicting the effects of layout changes before those often expensive changes are implemented. By inexpensively testing a number of options a wider array of possible solutions to usability problems can be examined quickly without spending the time and expense of user testing on each possible organization. Although this measure does not take every constraint into account, WA reflects one aspect of a complex environment. Multiple measures of behavior are key to this type of analysis because only the convergence of qualitative and quantitative measures reflect the construct of usability.

WA is a tool that predicts the improvement or decrement in task efficiency produced by a layout change. It should be used in situations where efficient task performance is crucial and must not be degraded for the sake of other concerns. Emergency medicine and

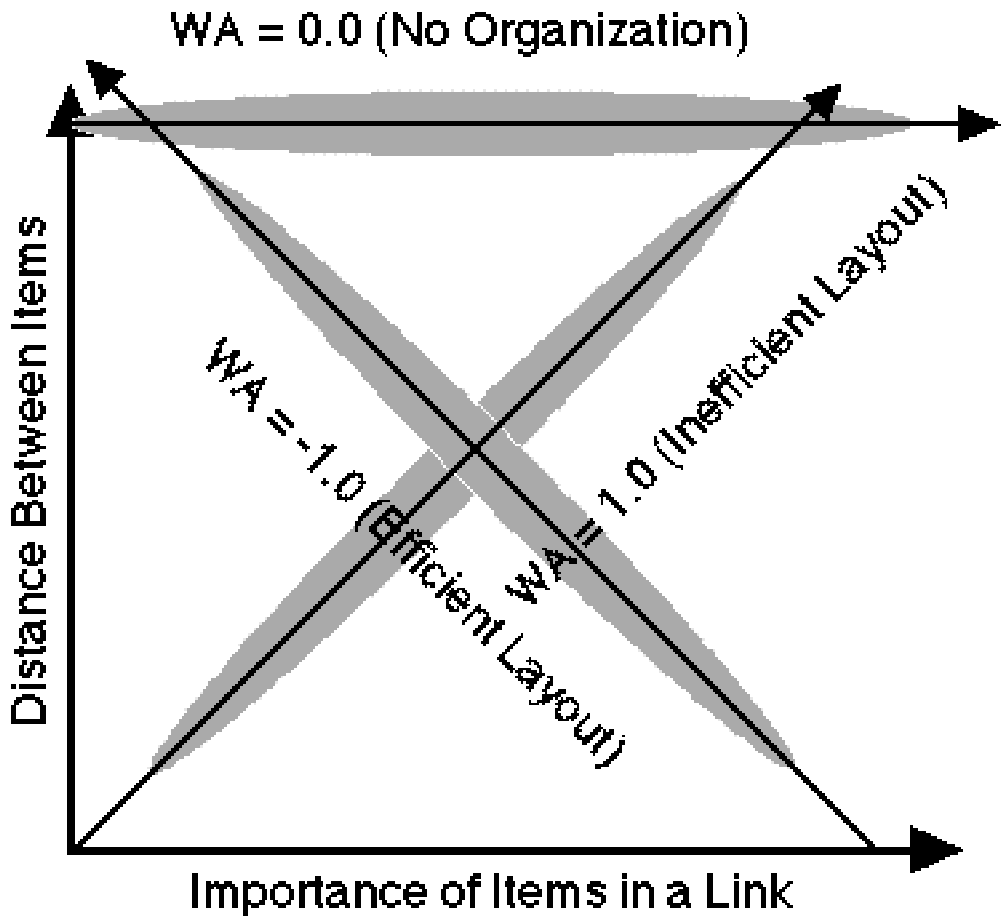

Figure 8.4: The Workspace Appropriateness score. High link importance values correspond to short distances. Because the placement of objects in many workspaces is constrained, Workspace Appropriateness scores tend to be grouped around the center point of this scale, 0.0. An ordinal interpretation of Workspace Appropriateness scores (i.e.; Layout B is more efficient then Layout A) is more applicable than a magnitude judgment (i.e.; Layout B is 34% more efficient then Layout A)

aviation are fields where task performance is crucial and may not be sacrificed for other less important reasons. In situations where ”trial and error” design decisions can have dire results, an effective method for modeling the spatial aspect of task performance, such as WA is required.

8.2 Auditory alarms

Problems associated with alarms have been identified (Weinger & Englund, 1990), yet little empirical data exists examining the extent of the problem. We attempted to quantify the use of alarms during emergency and elective airway management, a period of heavy workload and frequent alarms partly due to the transition from masked to mechanical ventilation. We hypothesized that 1) the more alarms occur from a device that are silenced, the more that device’s true alarms will be missed, 2) the more false alarms from a device, the more frequently and sooner that device’s alarms will be silenced.

8.2.1 Method

The activities of two types of auditory alarms—mechanical ventilator (Servo 900C) and CO_2 /pulse oximetry monitor (Nelco, ETPO) alarms—in video taped real-life airway management cases were recorded by the start and end time of each alarm and the time of each silencing act. Each alarm was coded as (1) a *false alarm* if it occurred during airway suctioning and laryngoscopy or was caused by poor signal or unused equipment, (2) a *missed alarm* if it was a true alarm but was not treated as such by care providers, and (3) a *silenced alarm* if it was silenced by a care provider. A computer program was written to control and to obtain timing information directly from video cassette recorders, and to enter coding. The period between mask pre-oxygenation before tracheal intubation and successful mechanical ventilation through the endo-tracheal tube was selected for coding. Videotapes of both operating room (OR) and resuscitation area cases were coded (both settings used the same kind of ventilators and ETPO). χ^2 test was used for comparison of numbers of silenced, false, and missed alarms, and t-test for comparison of alarm durations.

8.2.2 Results

Forty-seven cases (18 in OR s) were coded, with an average length of 468 (SD=234) sec per case. ventilator alarms sounded in 87% (n=41) and ETPO alarms in 66% (n=31) of the cases. The average total duration per case was 22 sec for ventilator alarms and 163 sec for ETPO alarms (Figure 8.5). The majority of alarms were false (Figure 8.6), but the difference between false ventilator and ETPO alarms was not significant. However, ventilator alarms were silenced 4 times more often and on average nearly 8 times sooner than ETPO alarms, and ventilator alarms were twice as likely to be missed (Figure 8.7).

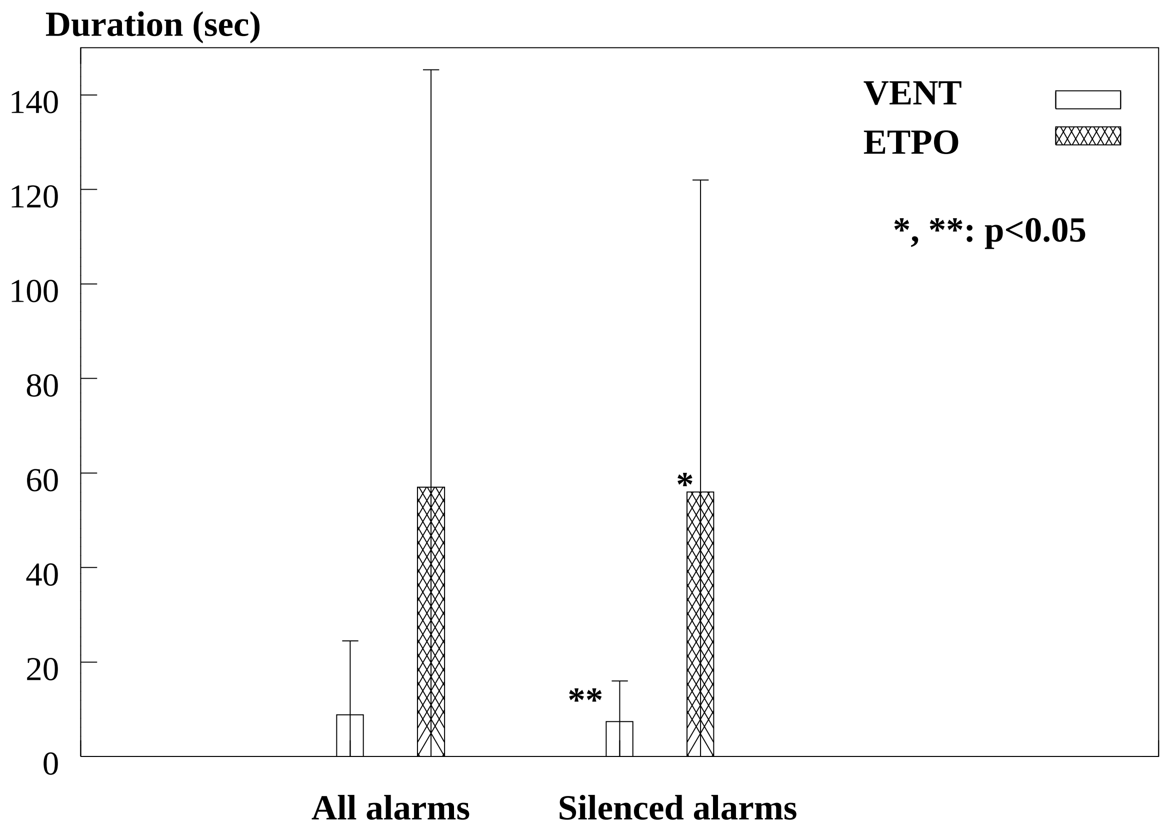

Figure 8.5: The duration of auditory alarms from ventilators and end-tidal CO2/pulse oximeter monitor. VENT: ventilator (Siemens 900), ETPO: end-tidal CO2/pulse oximeter monitor. Note that the ventilator alarms were silenced 4 times more often and nearly 8 times sooner than the ETPO alarms.

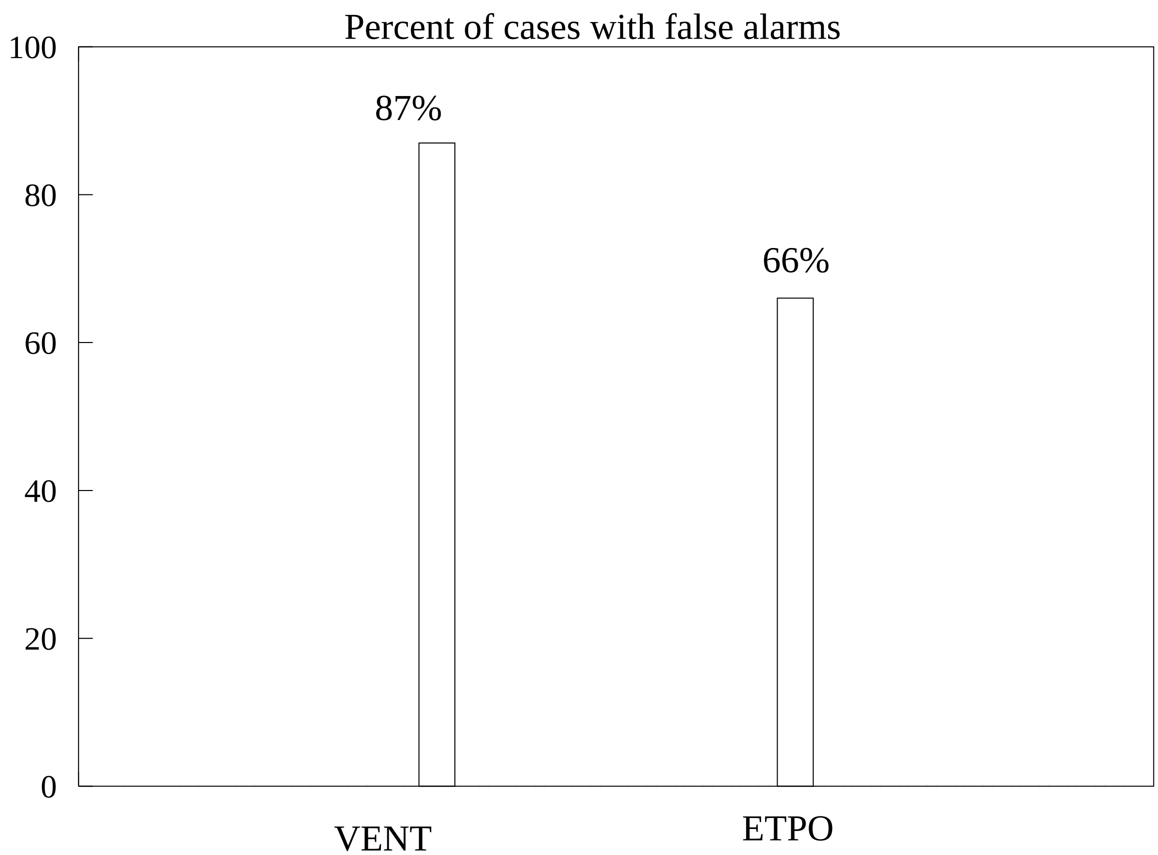

Figure 8.6: The occurrences of false alarms. VENT: ventilator, ETPO: end-tidal CO2/pulse oximeter monitor.

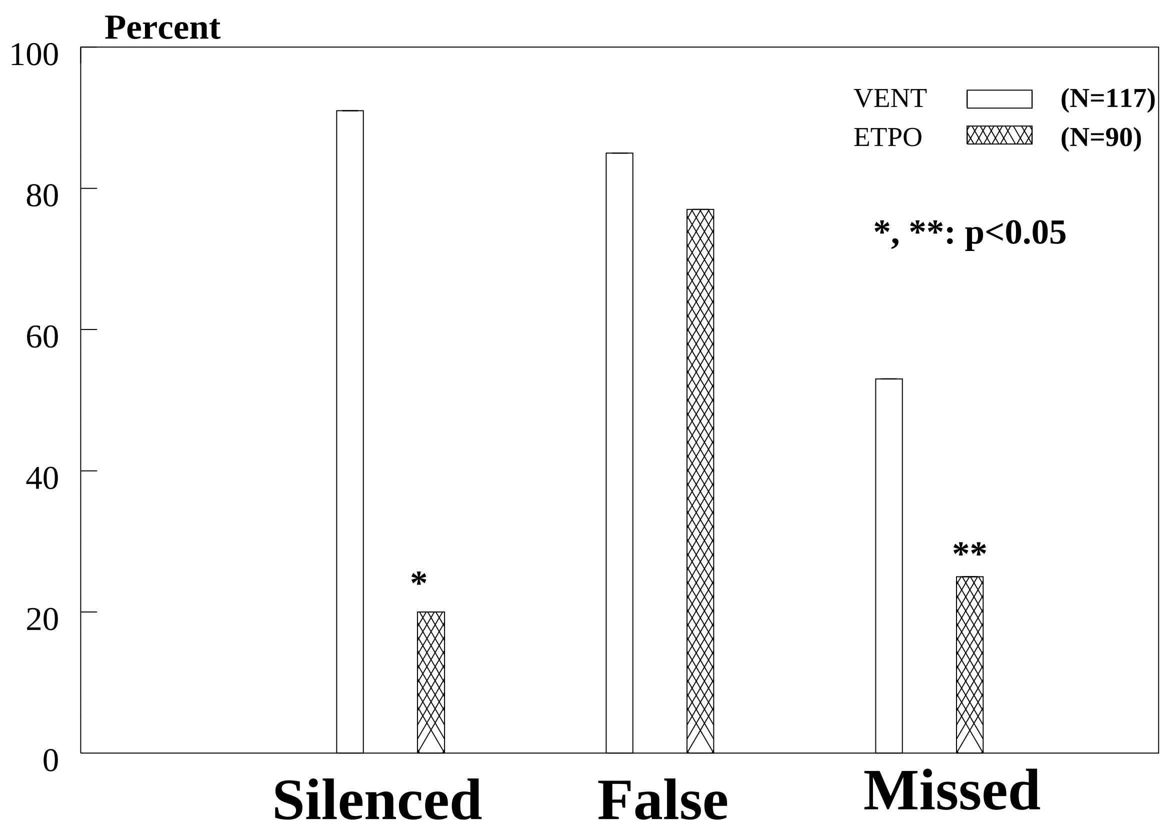

Figure 8.7: The rate of silenced, false, and missed alarms. VENT: ventilator, ETPO: end-tidal CO2/pulse oximeter monitor.

8.2.3 Discussion

The results support Hypothesis 1 but not Hypothesis 2. The continuous, loud ventilator alarm sound may make it hard for care providers to ignore and probably contributes to the difference in how the two types of alarms were silenced.

The presence of large number of alarms, most of which were false and were silenced, could negatively impact on the quality of patient care. Firstly, the 25–53% of true alarms silenced without investigating the cause of the alarm suggests that false alarms promote the "cry wolf syndrome." Secondly, the alarms pose extra workload (to push the silence buttons and interrupt the on-going task). Thirdly, frequent occurrences of alarms increase the stress to care providers and distract their attention. Last but not least, auditory alarms produce a noisy work environment which makes it difficult to communicate and to detect other auditory signals.