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Characterizing Navigational Tools in a Virtual Search Task

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CHARACTERIZING NAVIGATIONAL TOOLS
IN A VIRTUAL SEARCH TASK

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ABSTRACT

The goal of this thesis is to characterize and empirically compare navigational tools in the context of a virtual inspection task. The framework considers both directional-cue navigational tools (e.g., GPS navigation arrows) and trail navigational tools (e.g.,footprints) in comparison to a control condition. Characterizing the tools allows for documented relationships between specific navigational tool-performance combinations.

It is intended that by characterizing and comparing the tools a more advantageous use of navigational tools will emerge to increase the benefit provided to both the users and implementers of virtual environments. The focus of the metrics in the paper were distance traveled, speed of travel, and average target acquisition time (via SATO analysis) due to their presence in the literature. Targeted recommendations can be made based on the level of participant's experience with virtual environments, or a general recommendation can be made based upon desired performance metric.

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CHAPTER ONE

INTRODUCTION

The primary goal of this thesis is to provide a structured characterization of, and empirical comparison between, select navigational tools used in a virtual inspection task. The framework of the study allows for consideration of both directional-cue navigational tools (e.g.,GPS navigation arrows) and trail navigational tools (e.g.,footprints) in comparison to a control condition. The characterization of navigational tools allows for a documented relationship between task performance and specific tool combinations. The comparison of navigational tools to each other and the control condition allows for the selection of the best tool given the desired performance metric(s) for a virtual inspection task.

Along with the increasing popularity and number of virtual environments, the number of navigational tools for these environments has similarly increased, but without an accompanying comparison of the tools (Burigat & Chittaro, 2007). By characterizing and ranking the tools in the context of a search task, it is intended that a more advantageous use of navigational tools will emerge to increase the benefit provided to both the users and implementers of virtual environments. The tools were measured in terms of their distance traveled, speed of navigation in the environment, and speed-accuracy tradeoff (SATO), which not only provide a characterization of the tool, but can ensure that the implementer is focusing on the desired area of performance.

Chapter 2 provides background information and a literature review on the topics considered in this thesis, including the transfer of knowledge from a virtual environment, usage of navigational tools in virtual environments, and visual search tasks. Chapter 3 discusses the justification for the approach and defines the experiment and analysis approach implemented in this thesis. In Chapter 4, the results of the data analysis are discussed in conjunction with the categorization and comparison of the navigational tools used in this study. Chapter 5 discusses the implication of these results within the context of the literature and the categorization of the tools as well as the implication of the selection and impact of navigational tools for the selected scenario. Lastly, generalized conclusions and recommendations for future improvement and future studies are suggested.

CHAPTER TWO

LITERATURE REVIEW

The literature review will begin with information on virtual environments and some of the applications. Navigation in a virtual environment will also be discussed in terms of mental maps and how this relates to navigational tools. Lastly, the topic of visual search and its relation to the speed-accuracy tradeoff will be covered.

Virtual Environments and Applications

Virtual environments have become increasing utilized for a wide range of applications including training, education, evaluation, marketing and therapy (Stanney, Mourant & Kennedy, 1998; McLay et. al., 2014; Hall, Stiles & Horwitz, 1998) and domains such as medicine (Stanney, Mourant & Kennedy, 1998), engineering, education(Kizil & Joy, 200;1 Scerbo, 2004), design, entertainment, healthcare (McLay et. al., 2014), industry, and military (Witmer, Baily, Knerr & Abel, 1994). There are different types of VEs including desktop, head-mounted displays (HMDs) and computer-aided virtual environments (CAVEs). One way that these VEs may be differentiated is by the degree of immersion they provide. Immersion, which may be used interchangeably with presence in conversation, is distinctly separate when referred to in the context of virtual environments. Immersion is the degree to which equipment contributes to the visual fidelity, or “realness,” or a participant’s experience, whereas presence is the psychological sense of “being there” (Slater & Wilbur, 1997).

The current research can be grouped into three categories: performance of participants; health and safety issues; and social implications (Stanney, Mourant & Kennedy, 1998). The health and safety category covers issues ranging from discomfort (e.g.,simulator sickness) to harm (e.g.,epileptic seizures) as a result of either physical or psychological causes. The social implication category covers the possible effects on social interaction both inside and outside the VE (Stanney, Mourant & Kennedy, 1998). The purpose of this thesis is to aid in maximizing task performance in VEs. This area of research covers a broad range of topics including VE interaction techniques (e.g.,Bowman, Johnson & Hodges, 1999), visual cues (e.g.,Lu, Duh & Feiner, 2012), and auditory cues (e.g.,Dodiya & Alexandrov, 2008). An individual's performance in a VE is also reliant upon the task characteristics and individual characteristics, such as experience or gender (Stanney, Mourant & Kennedy, 1998). One of the effects of having so many different applications with the possibility for different methods of interactions is the number of support tools, including navigational tools, has greatly propagated. The majority of these tools are not compared in the existing research, meaning there is a gap in the literature that could potentially allow for the comparison of tools.

Navigation in VEs

One of the most important functions performed in a VE is navigation (Bowman, Kruijff, LaViola & Poipyrev, 2004). Navigation is a function that is executed to fulfill the purpose of moving through an environment. It has two primary steps: wayfinding and travel (Bowman, Davis, Hodges & Badre, 1999). Wayfinding is the cognitive step during which a route is planned and travel is the execution of that route. Wayfinding can then be further broken down into (1) orientation, (2) route decision, (3) route monitoring, and (4) destination recognition (Dodiya & Alexandrov, 2008). Travel, of course, is moving through the environment. An overview of the structure of navigation can be seen in Figure 2.1.

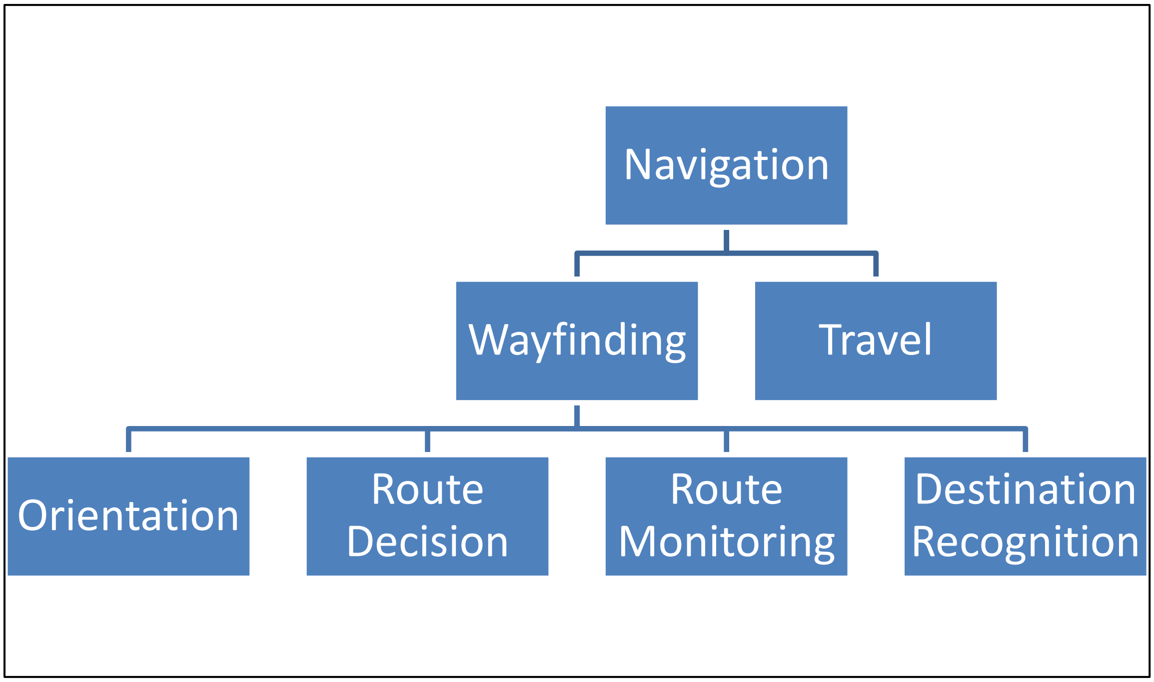


Figure 2.1: Process of Navigation

In particular, orientation is an important prerequisite for successful navigation (Bowman, Davis, Hodges & Badre, 1999). It is defined as a participant's sense of their position and heading. Moreover, it can be separated from the subsequent (wayfinding) steps in that it is not a decision making process and is performed before travel. Orientation can be affected by the mode of travel (Chance, Gaunet, Beall & Loomis, 1998) and gender (Sandstrom, Kaufman & Huettel, 1998). It may also directly affect navigational performance (Bowman, Davis, Hodges & Badre, 1999; Lessels & Ruddle, 2005) and therefore the transfer of desired information to the physical world. Successful navigation, specifically the wayfinding step of navigation, requires an accurate cognitive map (Thorndyke & Hayes-Roth, 1982; Waller, Hunt & Knapp, 1998). A cognitive map is a mental representation of an environment, physical or otherwise (Eden, 1992). Cognitive maps have been a focal point of current research into navigation (Bodily, Daniel & Sturz, 2012), including the information stored within a cognitive map (Gillner & Mallot, 1998) and the utilization of that information (Stankiewicz, Legge, Mansfield & Schnlicht, 2006). In general, the creation of a cognitive map is slower when interacting with a VE than when interacting with a physical environment (Richardson, Montello & Hegarty, 1999). In order to help offset the slower creation and the subsequent utilization of these cognitive maps, various navigational tools have been created and implemented in the form of maps (Darken & Cevik, 1999), landmarks, geometric information, visual cues (Sandstrom, Kaufman & Huettel, 1998), and auditory cues (Dodiya & Alexandrov, 2008). Although there is a wealth of tools to choose from, and an even greater number of VEs and tasks with which they may be paired, there is a lack of analyses and usability studies concerning this set of options.

The knowledge concerning physically interfacing with VEs is currently better established than the effects of navigational tool on VE interaction (Bowman, Johnson & Hodges, 1999; Ryden et. al., 2011, Youngblut et. al., 1996). Although some interfaces may be more intuitive than others for navigating a VE or a mode of travel (e.g.,using a joystick to simulate flying), experience also plays a role in task performance (Burigat & Chittaro, 2007). For this reason, along with cost (Youngblut et. al., 1996), it can be practical to use a keyboard and mouse interface for application to a general audience and for navigating on foot (compared to driving a virtual car). The added significance is that to maximize the effectiveness of any chosen navigational tool, the interface devices must be considered (e.g.,Ruddle & Lessels, 2009). Although devices such as head-mounted displays may be associated with the level of immersion (Pausch, Proffitt & Williams, 1997), it is important to separate the impact from immersion and the impact from a good control scheme as separate concepts.

Visual search

Visual search is any inspection task that does not utilize machine-enhanced methods (e.g.,x-ray, thermography) (Drury & Watson, 2002). Although strongly associated with manufacturing, it is also used in maintenance, security, design review, and functionality determination (Drury, 1992) in conjunction with other inspection techniques (Drury & Watson, 2002; Vora et. al., 2002). Inspection tasks are expected to be accurate, timely, flexible (i.e., capable of dealing with multiple nonconforming conditions), and stable (i.e., the process does not change through repeated use).

In particular, accuracy, one of the most important considerations of inspection, has a strong relationship with the amount of time spent on the task (Drury, 1992; Drury & Watson, 2002). This relationship between accuracy and time, known as Speed-Accuracy Trade-Off (SATO), is well documented in many tasks, including visual search. In visual search tasks, accuracy is based upon the time spent searching. The relationship indicates that as more time is spent on inspection, the chance of identifying nonconformities approaches 1. For the purpose of this thesis, the inspection task being emulated is being performed by an individual walking a factory floor. This means that a navigational tool must be chosen to suit an on-foot inspection task being performed with a mouse and keyboard.

Gaps in the Literature

There remains an opportunity to explore the impact of navigational tools on performance within a virtual environment. Specifically, it is valuable how navigational tools affect the SATO relationship changes depending on navigational tools and the experience level of individual participants. For distance, it is import to identify which tools result in greater or lesser distances traveled. By understanding the effect of these different navigational tools on performance, it may be possible to select tools based upon the desired performance metric or individual's experience to attain improved results. This will also aid future research in examining the impact of navigational aids on performance in different environments and different tasks.

CHAPTER THREE

METHODOLOGY

Participants

One-hundred and seventy-one participants (94 male, 67 female, and 10 unreported), with a mean age of 21.15 (SD=4.18, were recruited via email and YouTube, paper flyers, and word-of-mouth advertising. The participants were compensated by their choice of a $10 gift card, or through course credit if applicable.

Participants reported their frequency of computer use and degree of experience with virtual reality and video games. While 169 participants reported using a computer daily (two unreported), experience levels appear to be fairly evenly distributed, as seen in Figure 3.1.

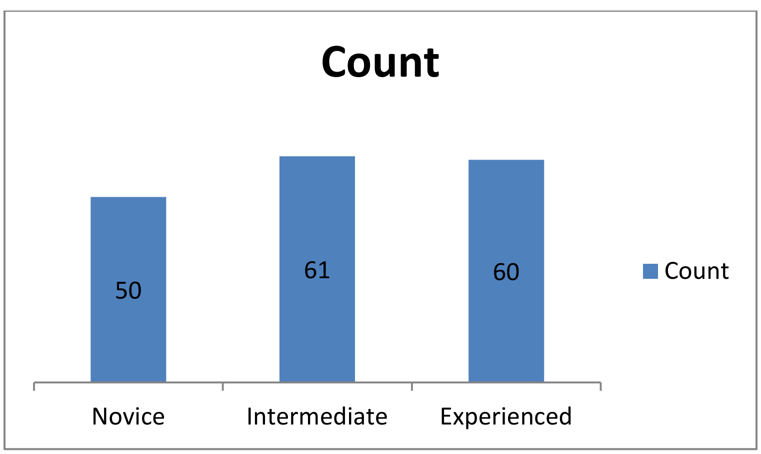


Figure 3.1: Frequency of Experience Levels Among the Participants

Tabulating the experience levels with gender shows that while the portions of both male and female intermediately experienced participants appear even, the majority of experienced participants are male and the majority of novice users are female (see Table 3.1). All participants were also screened (via a survey) for vision and hearing deficiencies, English fluency, and for medical conditions that might be exacerbated by the VE (e.g.,epilepsy).

Frequency Row %	Experienced	Intermediate	Novice	Total
Female	4 5.97	23 34.33	40 59.70	67
Male	52 55.32	34 36.17	8 8.51	94
	56	57	48	161

Table 3.1: Experience by Gender Level

Apparatus

The study was conducted using a computer workstation with a desktop computer running Windows Vista. Five workstations, separated by partitions, were used to run participants. The VE, which represented an automotive assembly facility, was created using the UNITY programming language (Chandy & Misra, 1988; Unity Game Engine, 2014). The VE included safety violations occurring at predetermined locations, and tracked participant performance with regard to these violations. The participants' coordinates were also recorded at a rate of 60 Hz, allowing for the participant paths to be retraced. There were both screening and exit surveys; these were digitized and administered through REDCap via a web browser

(Harris, et al., 2009). All of the data that was collected during the study was securely stored on a Clemson server.

Experimental Task and Design

The experimental task was to identify and classify all safety violations (there were 25 violations) while navigating throughout the VE. The layout of the VE and the location of the safety violations remained the same across all conditions. There were nine between-subject conditions generated by a 3^2 design. The two factors were: (1) Path and (2) Trail. The path tools provided guidance for the participants by indicating the direction in which to travel, whereas the trail tools provided guidance for the participants via a visual travel history. The three levels of each factor were (1) none, (2) embedded, and (3) detached. The "none" level means that a navigational tool is not available, the embedded level means that the navigational tool appears in the VE, and the detached level means that the navigational tool appears on a map of the VE (see Figure 3.2 in Appendix A for examples). The end result was the nine conditions shown in Figure 3.3 in Appendix A.

Procedure

Before the participants arrived, the facilitators followed a seven-step checklist for ensuring consistent and thorough preparation for the participants (see Appendix B). This included setting up and testing computer workstations, placing participant handouts at each workstation, preparing documentation, hanging a "Do not disturb" sign, retrieving gift cards from a secure location, and ensuring all equipment was present and in working order. All of the hardcopy documentation and the flash-drive daily data backup were stored in secure locations.

Upon arrival, each participant was checked in and later received handouts after completing the consent process (Clemson University IRB Protocol # IRB20013-236). These handouts contained an overview of the study and step-by-step instructions for navigating the VE (see Appendix B). Once all of the participants were present for a particular session, or at the designated start time, the facilitators read from the dialogue shown in Appendix B and invited participants to begin.

The next phase begins with a safety training presentation, ensuring that all participants had basic knowledge pertaining to the safety violations that would appear in the VE. The participants would later use this information to identify violations and specify their classification (e.g., electrical hazard, safety guard hazard, etc.). The presentation was a timed PowerPoint that contained a voiceover and video clips (shown in Appendix C). The presentation also served the purpose of showing participants how to switch between the necessary program windows on the computer. After watching the presentation, the participants entered the VE where they completed a tutorial taking them through how to navigate the environment and showing how to select and classify a violation. (This violation did not appear in the test environment.) Upon completing the tutorial, the VE transitioned to the test environment where the participant was tasked with identifying as many safety violations as possible. No reference to the role of navigation was made. The participants had the ability to freely roam the VE, unrestricted by their particular navigational tool. Participants also had the ability to leave the environment at their own discretion by approaching an exit door where they would receive a prompt to quit. Upon completing this task, the participants began an exit survey, which included several questionnaires: (1) NASA Task Load Index (TLX) (Hart & Staveland, 1988), (2) a presence questionnaire (Witmer et al., 2005), and (3) the IBM Computer Usability Satisfaction Questionnaire (CSUQ) (Lewis, 1995) (see Appendix D).

Independent Variables

The independent variables used for this study are (1) the navigational tool condition and (2) the level of experience with computer/video game experience (as a covariate). The structure of the navigational tools was a 3^2 design resulting in 9 different experimental conditions shown in Figures 3.4. The level of experience was categorized into one of three levels: (1) novice (less than 10 hours), intermediate (between 10 and 500 hours), and expert (greater than 500 hours), based upon responses from the questionnaire.

Dependent Variables

As the goal of this thesis is to provide a meaningful and structured characterization of and comparison between navigational tools, four dependent variables were chosen: (1) distance traveled, (2) speed traveled, (3) accuracy, (4) target acquisition time (SATO). The shortest path to complete the task was identified and the distance measure was calculated as the number of path lengths each participant traveled. This was done to provide context to the amount of distance traveled compared to that of the suggested path. The length of the path traveled is an important measurement in scenarios where there is a limited amount of movement allowed.

The speed with which a participant traveled was the average speed in the test environment (m/s). The speed of travel is an important measurement in scenarios where there is a potentially large area to search or when easily distinguished search targets are geographically separated. The accuracy of a participant was measured directly as the number of violations found (out of the potential 25), which was later converted to a percentage. The target acquisition time is the average time taken to identify one violation. This is important for characterizing the efficiency of navigational tools as a lower target acquisition time will result in an SAOC curve representing a more efficient relationship. The measures of time and distance traveled correspond to measures previously reported in related literature (e.g., Ruddle, 2001; Lessels & Ruddle, 2005; and Burigat & Chittaro, 2007).

Hypotheses

In characterizing the navigational tools there are six separate hypotheses that will be addressed.

Hypothesis 1. Different tools will result in different distances traveled.

Hypothesis 2. Different conditions will result in different travel speeds.

Hypothesis 3. Speed of travel will differ between groups with different levels of experience.

Hypothesis 4. Different conditions will result in different task efficiencies.

Hypothesis 5. Efficiency (with regard to task performance) will differ between groups with different levels of experience.

Hypothesis 6. The correlation between accuracy and time will differ between conditions.

CHAPTER FOUR

RESULTS

To determine the presence of significant differences existing among the dependent variable means across the multiple conditions, a series of ANOVAs were performed. Post-hoc Tukey's comparisons were used to test for significant differences among specific means. All test were assessed at the 5% Type I error level. JMP was used to perform the calculations. The models for the ANOVAs were based on a full-factorial treatment design for the independent variables of path and trail, and experience was included in the model as a covariate. Gender was not included as a covariate due to the fact that it was strongly correlated with experience, and thus would be a redundant measure introducing multicollinearity (see Figure 4.1).

Count Row %	Experienced	Intermediate	Novice	
Female	4 5.97	23 34.33	40 59.70	67
Male	52 55.32	34 36.17	8 8.51	94
	56	57	48	161

Table 4.1: Covariate Relationship

Distance

Characterized by Condition. The distance measure was determined by measuring the distance traveled in the VE, starting when entering the test environment and ending when the program closed, and then dividing by the length of the suggested path from the path conditions. The result is a ratio showing how far the participant traveled compared to the suggested path. The result is identical to using standard distance, but it gives context to the values of distance. Using distance as the dependent variable and paths, trails, and experience level as the independent and covariate variables respectively, the model shown in Table 4.2 was generated.

Paths Tukey's Test		
Level	**Connecting Letter**	**Least Sq Mean**
None		2.13
Detached	B	1.50
Embedded	B	1.36

Table 4.2: Distance versus Paths

Paths were shown to be the only factor that significantly affected distance traveled ($F=24.63$; $p<0.0001$). The control resulted in a significantly greater distance traveled ($M=2.13$; $SE=0.08$) than both the detached level ($M=1.49$; $SE=0.08$) and embedded level ($M=1.36$; $SE=0.08$). Comparing all nine conditions individually to find the most and least effective tools yields the model shown in Table 4.3. The control, ET, and DT were significantly greater than EP/ET. Addressing hypothesis 1, it is seen that the conditions have a significant effect on distance.

Condition Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
C	A	2.31
DT	B	2.05
ET	B	2.04
DP	A	1.54
DP/DT	B	1.52
EP	B	1.45
DP/ET	A	1.41
EP/DT	B	1.40
EP/ET	B	1.24

Table 4.3: Distance by Condition

Distances can be further explored by examining heatmaps tracking participants' travel. By pairing maps with data it is possible to get a more complete image of events. Looking at Figure 4.1, for example, it is seen that the control participants had a tendency to more randomly explore the first isle indicated by a broader coverage of light lines, but congregated toward a common path in the third isle indicated by narrower coverage of dark lines.

Figure 4.1: Control Participant Heatmap

Speed of Navigation

Characterized by Condition. This measure was determined by dividing the distance traveled in the test environment by the time spent traveling that distance. Using speed as the dependent variable and paths, trails, and experience level as the independent variable, the model shown in Table 4.4 was created.

Paths Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
None	A	3.62
Embedded	A B	3.34
Detached	B	3.17
Experience Level Tukey's Test		
Experienced	A	3.95
Intermediate	B	3.37
Novice	C	2.80

Table 4.4: Speed versus Paths and Experience

Both paths (F=5.48; p=0.01) and experience level (F=34.25; p<0.0001) were shown to significantly affect the speed of navigation. The control (M=3.66; SE=0.09) was shown to be significantly greater than the detached level (M=3.19; SE=0.09). Neither of these conditions differed from the embedded condition (M=3.36; SE=0.09). The experienced participants (M=3.96; SE=0.09) also showed a significantly greater speed than intermediate participants (M=3.37; SE=0.09), which in turn was greater than the novice participants (M=2.80; SE=0.10). Comparing all nine conditions individually to find the most and least effective tools yields the model shown in Table 4.5. This second analysis shows that experience (F=32.61; p<0.0001) was the only factor significantly affecting speed. Similarly, the experienced participants (M=3.96; SE=0.09) were faster than the intermediate participants (M=3.37; SE=0.09), who in turn were faster than the novice participants (M=2.80; SE=0.10). Addressing hypothesis two, it is seen that condition affects the speed of travel. Addressing hypothesis three, it is seen that experience level affects the speed of travel.

Experience Level Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
Experienced	A	3.96
Intermediate	B	3.38
Novice	C	2.80

Table 4.5: Speed by Experience Level

Grouped by Experience. This analysis was performed by repeating the previous analysis but subdivided the data based upon experience level, effectively removing experience as a covariate. The model is shown in Table 4.6.

Condition Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
DT	A	4.82
EP/DT	A B	4.24
ET	A B	4.13
C	A B	4.06
DP	A B	3.86
EP	A B	3.85
DP/DT	A B	3.64
EP/ET	B	3.61
DP/ET	B	3.56

Table 4.6: Speed versus Condition Subsets by Experience

The goal behind dividing the data into subsets is to reveal which navigational tools would contribute most to the speed of each group. The analysis shows that experienced participants (F=2.30; p=0.03) do derive different effects from different navigational tools, with the detached path tool (M=4.80; SE=0.26) appearing to be the 'fastest' navigational tool.

SATO

Characterized by Condition. To determine the relevance of analyzing SATO differences, a model was created to determine if a SATO relationship was present. The resulting model, shown in Figure 4.7, is in analogous to the research that an inspection task is subject to a speed (time) accuracy tradeoff (Drury & Watson, 2002).

Experience Level Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
Experienced	A	21.86
Intermediate	B	19.62
Novice	B	18.45

Table 4.7 Accuracy versus Experience

With the relationship confirmed, the efficiency of the individual tools was measured against the condition and experience. This efficiency measure was determined by using the average time between identifying violations (target acquisition time) for each condition. For experience, the Tukey's comparison shows that the experienced participants (M=14.41; SE=0.75) were more efficient than both the novice (M=21.55; SE=0.81) and intermediate (M=18.74; SE=0.74) participants (see Table 4.8). Addressing hypothesis four, it is seen that different conditions affect efficiency of task performance. Addressing hypothesis five, it is seen that experience affects efficiency of task performance.

Condition Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
C	A	22.66
ET	A B	21.27
DP	A B C	18.53
DT	A B C	18.15

DP/ET	A B C	17.49
EP/ET	A B C	17.21
DP/DT	B C	16.74
EP	B C	16.05
EP/DT	C	15.55
Experience Level Tukey's		
Experienced	A	21.54
Intermediate	A	19.05
Novice	B	13.96

Table 4.8: SATO Analysis; Target Acquisition Times Against Condition and Experience

Characterized by Experience. This analysis was performed by repeating the previous analysis but on data grouped by experience levels. The model is shown in Table 4.9.

Intermediate Experience: Condition Tukey's Test		
Level	**Connecting Letters**	**Least Sq Mean**
C	A	3.96
ET	A B	3.38
DT	A B	2.80
DP	A B C	3.96
EP/ET	B C	3.38
DP/ET	A B C	2.80
DP/DT	C	3.96
EP	C	3.38
EP/DT	C	2.80

Table 4.9: SATO Subsets by Experience

The goal of this analysis was to reveal the most suitable navigational tool for participants of a given experience level. Only the intermediate participants (F=2.79; p=0.01) showed a significant dependence on the navigational tool.

Robustness of Tools. For this analysis the relationship between accuracy and time was measured for each level of experience. The rationale is that a significant relationship would indicate that a specific tool is insensitive to individual differences. A multivariate analysis was conducted to find correlations.

Condition	**Accuracy vs. Time Correlation Coefficient**
Condition 2 - ET n = 22	R = 0.53
Condition 4 - EP n = 19	R = 0.61
Condition 8 – DP/ET n = 17	R = 0.69

Table 4.10: Accuracy versus Time Subsets by Condition

The model for this analysis is shown in Table 4.10. The results identified three relationships with significant correlation: the embedded trail conditions (R = 0.53), the embedded path condition (R=0.61), and the detached path-embedded trail (R=0.69) had the strongest correlations. Addressing hypothesis six, it is seen that different conditions exhibit different relationships.

CHAPTER FIVE

DISCUSSION

The purpose of this thesis was to characterize selected navigational tools in regard to performance measures during a visual search task. Not only were the navigational tools found to influence the distanced traveled, the speed of travel, and the efficiency of the visual search, but they were also found to affect participants differently based upon their level of experience. Experience was found to affect all of the measures except distance.

The results suggest that when given a recommended path, either via map or embedded into the environment, the participants traveled shorter distances because they tended to explore less (see Table 4.2). The lack of difference between the detached and embedded path may be due to the simplicity of the environment, and thus the simplicity of the path. When given a tool in such a situation there is little need for memorization or a precise cognitive map, eliminating the main advantages of a GPS-style embedded path. The analysis of distance against the nine individual conditions, showed that the control condition, the embedded trail, and the detached trail resulted in the largest amount of distance traveled (see Table 4.3). This may relate to the fact that although the trail helps to create a cognitive map, it only does so as the environment is traversed.

With the analysis of speed against paths, trails, and experience (see Table 4.4), it can be seen that the level of path tools and experience level will affect the speed of navigation. With the path tool, it is reasonable to assume that the high rate of travel in the control condition is a result of spending more time traveling through the environment and less time processing information. Therefore, the low rate of travel in the detached path condition may be related to dividing attention between the environment and the navigational tool. The effect of experience level on the dependent measures of interest may relate to: (1) cognitive map usage or (2) control interface proficiency. The first idea is that the participants with more experience can more effectively create a cognitive map from visual cues or navigational tools (Stanney, Mourant & Kennedy, 1998). The second idea is that more experienced participants may be able to more naturally move through the environment as they are more practiced at controlling their motion within VEs. While the speed versus condition analysis revealed that condition was not significant (see Table 4.5), the results very close to being so. A slight variation in either the environment or the task may lead to the navigational tools becoming a significant factor affecting the rate of travel.

When partitioning the speed versus condition based upon experience (see Table 4.6), it is shown that certain populations will derive different benefits from the navigational tools. It is suspected that for the experienced participants, it will matter what navigational tool is used if maintaining a high rate of travel is the goal.

Once the existence of a SATO relationship has been established (see Table 4.7), the following analysis revealed that both navigational tools and experience levels generate significant differences in search efficiency (see Table 4.8). In the Tukey's analysis of conditions, the two least efficient tools (control condition and embedded trail) were the same tools that resulted in the highest distances traveled. This may suggest that although the participants traveled a greater distance, they also retraced more ground, thus taking more time to find a new safety violation. The most efficient tool, the embedded path/detached trail tool, could be a result of better time management. By using the embedded path, the participant would not have to wayfind before traveling as they would when using a path located in a map. The detached trail would then help create a cognitive map by informing the participant where they have already traveled. The advantage that the detached trail would have is that the information can be accessed from anywhere since all of the information remains within sight, unlike the case with the embedded trail. Together, this means that the participant can start traveling with minimal wayfinding activity using the embedded path, and then only use the detached map for updating the cognitive map and wayfinding when necessary. Similarly the differences in experience levels could be explained by a more efficient use of time by the expert users. This is seemingly reinforced by the analysis in Table 4.9 where it is revealed that although the experienced participants are more efficient, it is not due to differences in the navigational tools; they utilize all tools more efficiently. The opposite is also a likely explanation for the low efficiency of the novice users: they are unable to efficiently use the information at their disposal. The intermediate participants are somewhere in-between; whereas the novice cannot utilize the information at their disposal and the experts have “outgrown” their need for the information, the intermediates are able to glean useful insight from the navigational tools.

Additionally, there is evidence that supports the concept that some navigational tools will be more resistant to individual differences (see Table 4.10). While the population recruited for the study was somewhat homogeneous (i.e., mostly college students between the ages of 18 and 30), there may be a need to utilize more robust tools when a more heterogeneous population is exposed to VEs. In these scenarios, it would be advantageous to use one of these robust tools.

SUMMARY

By dividing the tools into paths and trails, the effect of each factor on the dependent variables can be characterized. The path tool significantly affects both the distance and speed traveled. Having no path, the control condition seems to result in a greater distance traveled (than either the detached or embedded paths). The control condition also results in a greater rate of travel than the detached path tool, although the embedded tool does not significantly differ from either the detached or control conditions. Alternatively, the trail tools appear to not significantly differ with either distance or speed. If the experience level of a participant is known prior to entering a VE, then a more targeted recommendation may be possible. Comparing the individual conditions is more complex as there are many more variables. For ease of comparison, the differences between individual conditions are shown in Figure 5.1.

It is also worthwhile to note that there are trends based upon the experience of the participants. Most noticeably is that the greater the level of experience, the greater the speed the participants will travel. Experienced participants also appear to better utilize the Detached Trail over the Embedded Path/Embedded Trail and Detached Path/Embedded Trail conditions. The experienced participants also acquired targets at a faster rate than either the novice or intermediate participants. In general, it is can be seen that on no test did a lower level of experience rate more favorably than a higher level of experience; at best, they performed on par. Targeted recommendations are based on the desired metric and are compiled in table 5.1.

Desired Metric	Recommendation
Distance	• For increased distance, do not utilize paths or trails • It is recommended to use the control condition
Speed	• For increased speed, it is recommended to not utilize paths or trails. • Experienced participants travel fastest with detached trail when compared to EP/ET and DP/ET
Efficiency	• For increased efficiency, it is recommended to use the control condition.
Robustness	• For robust tools, it is recommended to use the ET, EP, or DP/ET conditions.

Table 5.1: Recommendations

Limitations

Perhaps the biggest limitation of the study is that while factors where different levels cause significant differences are located, the factors are not compared with regard to absolute differences. For example, we know that the levels of trail result in differences, but we did not identify how the levels of trail performance compare to path performance. All levels of path performance may be equal, but still perform greater than paths. The results of this thesis provide a good starting point for further research, but are not intended to be the sole factor in recommending navigational tools.

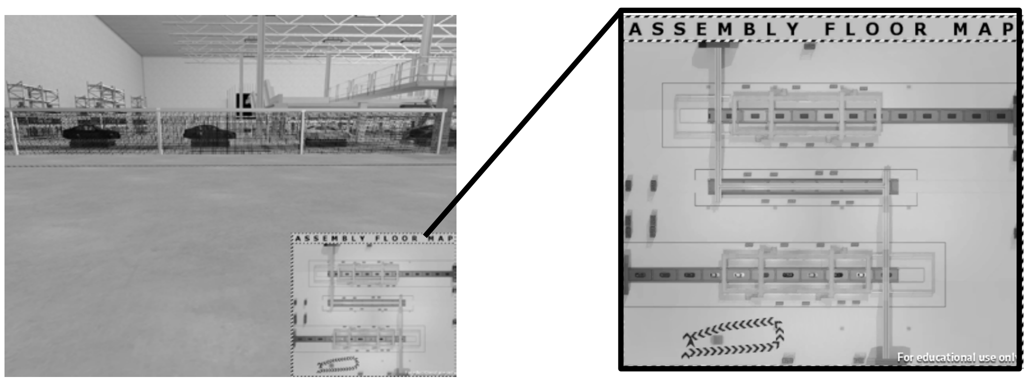
A second limiting factor is that although the experimental task provides a practical context for industry, the environment in which the task was carried out lacked complexity. The search targets were very conspicuous and perhaps did not mirror the same performance trends that would occur in a more realistic, complex environment. Additionally, the participant pool was homogenous which allowed a more nuanced evaluation with regards to experience levels. However, the results may not hold for heterogeneous populations. Future work should examine the effect of the tools in a more cluttered environment could lead to more accurate recommendations for broader applications. It is also recommended that the interaction between level of experience and navigational tools be studied in more detail to more provide more targeted recommendations.

APPENDICES

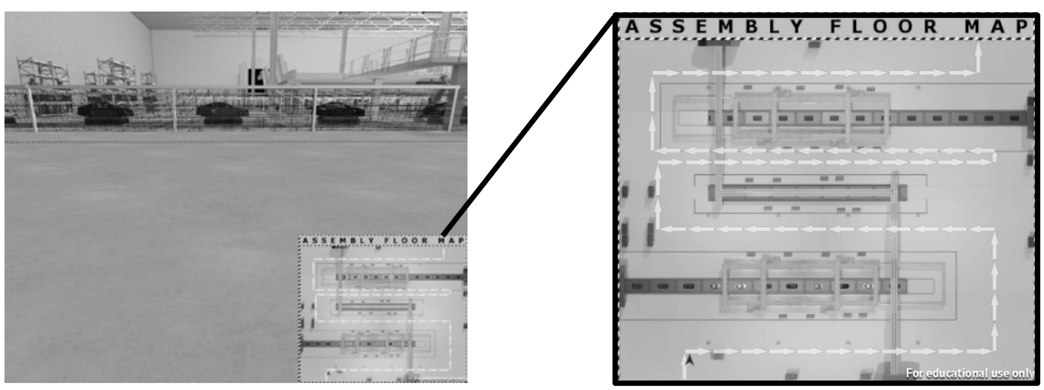
APPENDIX A: OVERSIZED FIGURES

(a) Embedded Trail

(B) Embedded Path



(C) Detached Path



(D) Detached Trail

Figure 3.2 (a-d): Embedded and Detached Aids

1-C **Control**	**2- ET** **Embedded Trail**	**3- DT** **Detached Trail**
4- EP **Embedded Path**	**5- ET/EP** **Embedded Trail** **Embedded Path**	**6- DT/EP** **Detached Trail** **Embedded Path**
7- DP **Detached Path**	**8- ET/DP** **Embedded Trail** **Detached Path**	**9- DT/DP** **Detached Trail** **Detached Path**

Figure 3.3: Navigational Aid Conditions and Designations

1 **C**								
	2 **ET**							
		3 **DT**						
D SATO			**4** **EP**					
D	D	D		**5** **ET/EP**				
D SATO	D SATO				**6** **DT/EP**			
D						**7** **DP**		
D							**8** **ET/DP**	
D SATO								**9** **DT/DP**

D – Significantly Differs by Distance Traveled

SATO – Significantly Differs by Rate of Target Acquisition

Figure 5.1: Comparison of Individual Conditions

APPENDIX B: PARTICIPANT INSTRUCTIONS

Instructions (Participant)

Overview:

This session consists of several activities:

1. viewing a safety training presentation;
2. completing simulator training along with a simulator exercise; and
3. completing an exit survey.

Please complete these step-by-step instructions, bearing in mind that you may quit at any time:

- Read and sign consent form and then turn it in to the facilitator.
- Listen to brief instructions from the facilitator.

1. View the safety training (PowerPoint) presentation which is already open in your browser. Use the headphones at your assigned workstation. Press the play button to begin.
2. Complete the virtual reality simulation training and subsequent exercise.
   a) Begin the simulation training by clicking the “Simulation” item in the task bar. Then follow the on-screen instructions.
   b) After completing the training, begin the simulation exercise by clicking the “start” button when prompted. In this exercise you will identify safety violations as you navigate the task environment.
3. Complete the exit survey regarding your experience in the task environment. Access this survey by clicking the item in the taskbar labeled “Exit Survey”.

- Go to a facilitator to receive your gift card or confirm your course credit.

APPENDIX C: FACILITATOR INSTRUCTIONS

Research Instructions (Facilitator)

Before Participants Arrive

1. Ensure that there is a sign on the computer lab door indicating a research study is taking place.
2. Ensure that all computer stations are on, logged in (using user ID: “subjectid”, password: “********”, properly numbered (e.g., with sticky notes), and have keyboards, headphones and mice.
3. Test headphone sound/volume.
4. Place Participant Instructions at each computer.
5. Open online spreadsheet (found on Clemson.box.com) which contains machine set-up. Set-up each workstation with corresponding conditions
6. Open online document for participants to record incentive option.
7. Locate gift card transaction document.

After Participants Arrive

8. As participants enter, record their name in the spreadsheet, give each a consent form, participant ID, and assign computer. Refer to the list of IDs and condition numbers.

Dialogue:

Thank you for taking the time to participate in our study. Please read and sign the consent form and turn it in to me if you wish to participate; then put on your headphones to listen to instructions by clicking the play button to begin the presentation. You will need the headphones for all activities except the exit survey.

Should you need to be reminded of these instructions, a handout has been placed by your computer.

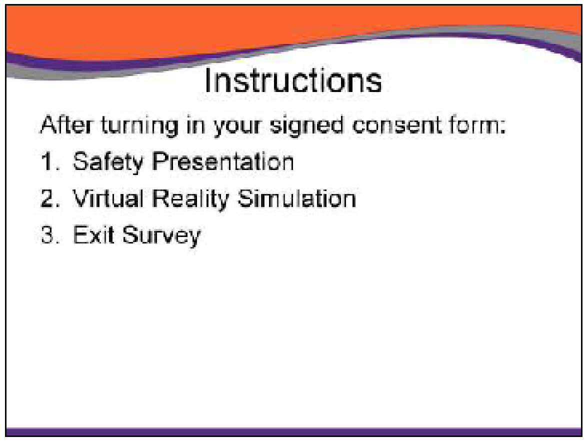
Once the study is over please see one of the facilitators to sign out and either receive your gift card or confirm course credit.

Please remember that you can ask questions or end your participation at any time. You may begin.

Before Participants Depart

9. Present gift card to subject unless they are in IE 2000 and have elected to receive course credit; log transaction (recipient must sign) or confirm course credit.

APPENDIX D: SAFETY PRESENTATION

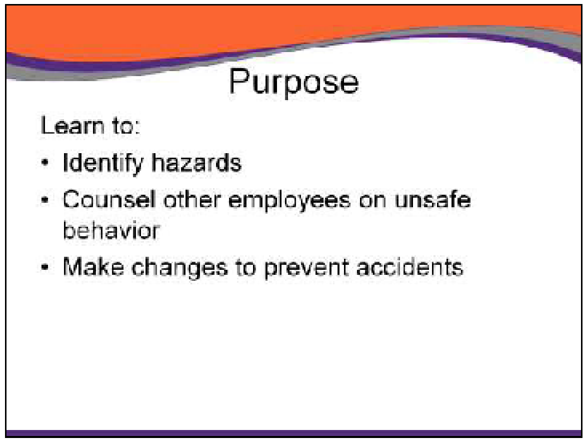


This study consists of three main activities. First you will view a presentation on safety in the workplace. Second, after a brief tutorial, you will take part in a virtual reality simulation where you will look for safety hazards in an industrial environment. After the simulation, you will be asked to complete an exit survey. When you are done with these three activities, see one of the facilitators to receive your gift card.

Please alert a facilitator of any questions you may have. If you need to be reminded of the instructions, you can refer to the printed handout. Also please remember you may end your participation at any time.

The safety training presentation will now begin. Please pay close attention because you will use what you learn to complete the next activity.

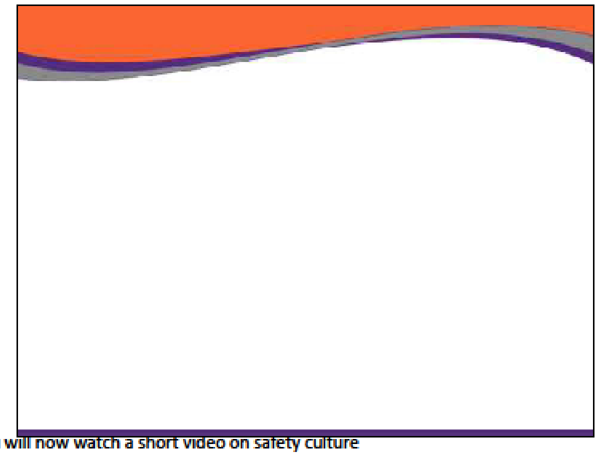
Welcome to a presentation on industrial safety.



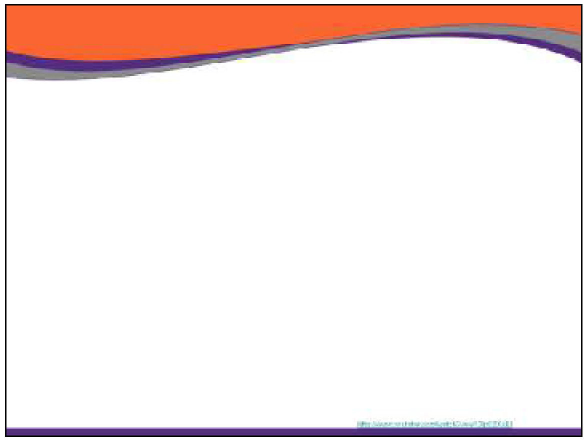
Successful safety programs rely on your ability to do these fundamental tasks: Identify hazards, counsel others on unsafe behavior and make changes to prevent accidents

Employees play an extremely important role in creating a safe work environment. The sooner you can develop a mindset that safety is a way of life, the better you can protect yourself and your co-workers from injury.

Let's explore how we can do our part by learning some of the common types of safety hazards so that we can identify them later on in an industrial environment.

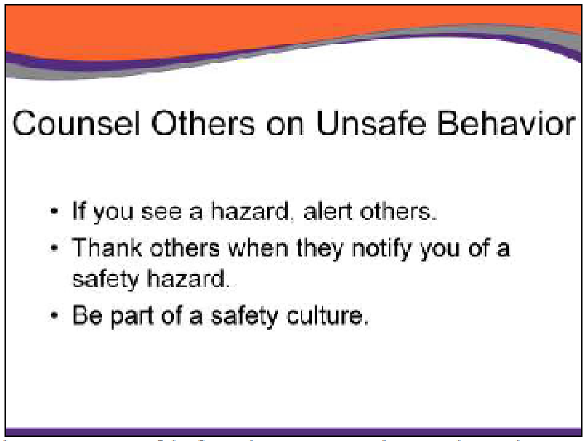


You will now watch a short video on safety culture



Now watch a short video on safety culture

http://www.youtube.com/watch?v=wF3JpEZXkEI



So as it turns out, successful safety cultures are ones where employees do not remain silent when they notice a safety hazard, such as not wearing proper personal protective equipment.

Instead, a safety culture, as it's often called, is one where employees look out for one another by alerting others of immediate danger or at-risk behaviors. If you see someone being unsafe, practice good safety culture by telling them. And if someone alerts you of a hazard or danger, listen to them, correct the problem and thank them. They may have just saved your life. Don't be afraid to speak up to someone. By doing this you play an active role in creating an environment where warning others is seen as a way of caring for others. Environments like this are known to have fewer accidents than those where workers passively accept the at-risk behaviors of others.

Don't stay silent. If you see something, say something. Make safety a way of life. That's what true safety culture is all about.

In your role as an active part of the safety culture you'll need to be able to identify various types of industrial hazards. Proper on-the-job training should help you learn to spot specific safety hazards that are unique to your work environment, but here are a few hazards that are seen universally and can be considered common safety violations. Let's explore each of them in more detail so that we understand what they mean and how to address these issues. We will discuss: poor housekeeping, slip, trip and fall hazards, exits not being clearly marked, missing fire safety equipment, electrical hazards, lacking machine guards, and lacking personal protective equipment.

Housekeeping is not just about appearances. In fact good housekeeping is necessary to prevent injuries, and it has the added benefit of maintaining an efficient, well-organized work flow.

You can avoid injury by practicing these safe behaviors:

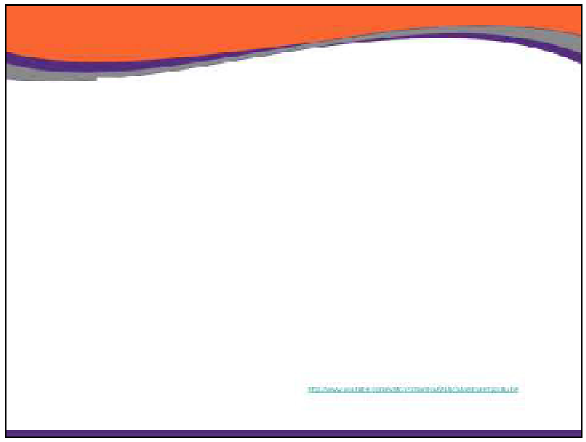
Keeping work areas clean and free of debris.

Keeping floors free of oil spillage or leakage.

Returning tools to their proper place.

Take a look at this short video to learn more.

[Video plays on next slide.]



http://www.youtube.com/watch?v=wr8GJytDjZo&feature=youtu.be

On a housekeeping side note – if there is a spill, and someone marks it using a wet floor sign, then they are still in violation because the hazard is still present. A known hazard like this can still cause an accident, and should be dealt with as soon as possible.

Remember good housekeeping involves: Keeping your work area clean and picked up, free of spills or leakage, and with every tool put back in its proper place.

In the case of a fire, explosion, medical emergency, chemical release or other situation that warrants evacuation, you should always have a way out. Being trapped in a dangerous environment is highly preventable if exits are properly marked and maintained. Exits should be clearly marked with illuminated signs. They are located in plain sight, usually above eye-level, along the path which leads to the outside.

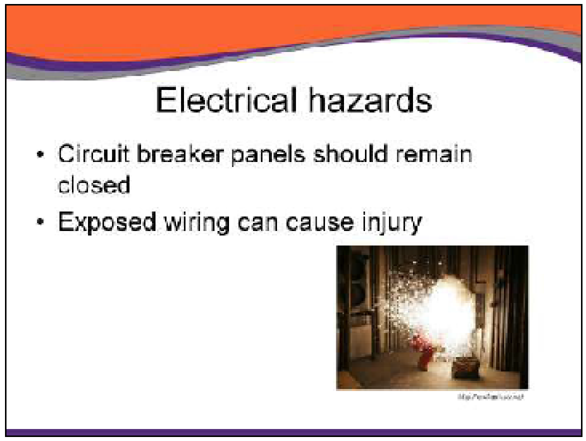
Pictured here are examples of exit signs. We use illuminated exits in case visibility is reduced by a loss of power or by smoke. Also notice how arrows on the sign indicate which way to exit.
Some exit signs use symbols instead of words in locations where not everyone may understand a common written language.
A standard place to display an exit sign is directly above a door which leads to the outside.

Because fire poses a significant risk to people and property, fire safety is an extensive topic that involves many industrial safety standards. These standards serve to minimize these risks through prevention and preparation. It is your employer's job to teach you the specifics of fire safety.

Fire safety training provided by your employer can teach you how to escape from a burning building by participating in regular fire drills.

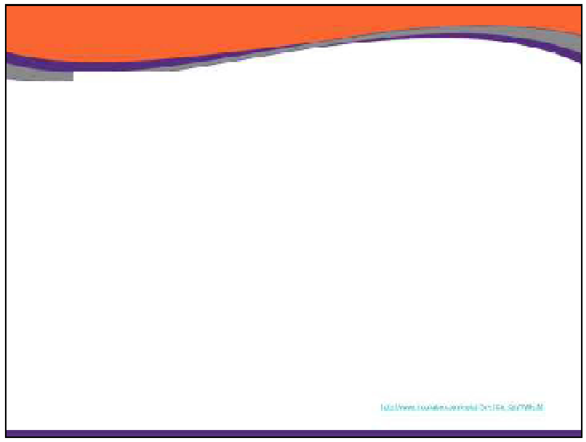
Also fire safety training can teach you how to stop a small fire before it can become a large fire by careful use of fire extinguishers or other fire safety equipment. However, do not attempt to fight a fire unless you are trained to do so because using the wrong type of fire safety equipment or using it improperly could worsen the situation.

Finally, fire safety training can teach you how to conduct fire safety inspections which serve to identify hazards and correct them before it is too late. Learn to identify fire safety equipment in your area. It usually has a permanent storage location marked with a safety color such as red. You can help to ensure that this equipment stays in its proper location and is well maintained. Regularly inspect your area to see that fire escape routes remain clear and clearly marked. If anything is out of place, don't remain silent. Instead, let someone know immediately so that the safety violation can be corrected.



Electricity can be extremely dangerous because often we cannot detect it until it's too late. Because of this, electrical equipment is designed with special safety features, but if these safeguards are not used properly, then they can become especially hazardous.

Working with electricity requires special training and should never be taken lightly. Remember to always heed warning labels. Often in an industrial setting, you may encounter high voltage circuit breaker panels. Never open these without proper training and personal protective equipment. If you see exposed wiring or notice worn extension cords or an open circuit breaker, alert a trained technician to correct the hazard immediately. Your employer should teach you more about electrical hazards that you may encounter such as arc-flash hazards.
Pictured here is an image of an arc-flash, which is a type of electrical hazard that can occur without warning. Dangers like this are an example of why you should steer clear of electricity unless are well equipped with specialized electrical training and safety equipment. [Photo http://arcflash.co.nz/]



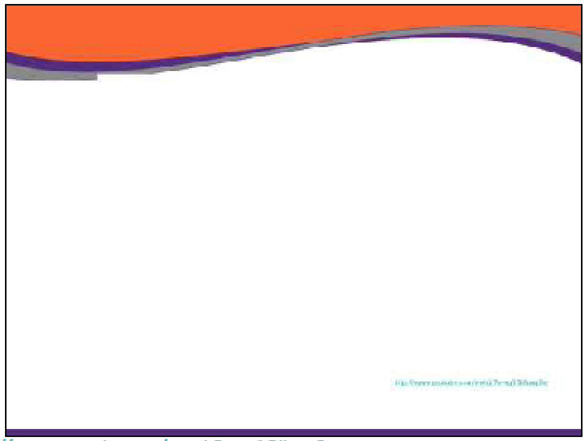
Now, let's watch a short video about machine guarding.

http://www.youtube.com/watch?v=1Cu_OiVW9mM

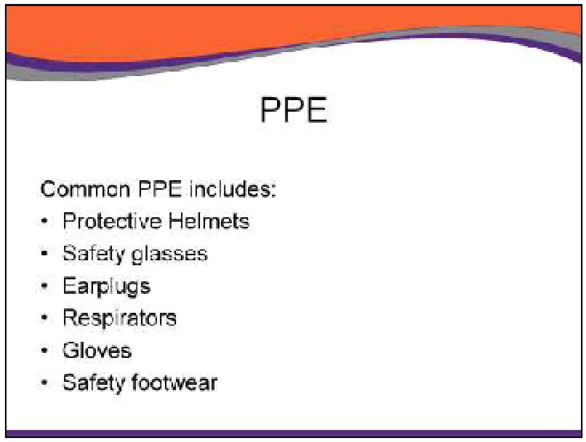
The last type of violation involves personal protective equipment, most commonly known as PPE. A list of common PPE is seen here. PPE is used when the hazard cannot be entirely engineered out of the process.

Because of this, it is critical that you use your recommended personal protective equipment. It is used as a last line of defense and it is often the only thing that stands between you and severe damage to your health and safety. Take a look at this video introducing PPE.

[play video]



http://www.youtube.com/watch?v=rg1GJluag6w



[after video]Requirements for PPE vary greatly depending on the nature of your work and each job will have its own specific set of PPE requirements. Ask your supervisor if you are ever unsure of what PPE you might need. Also, your personal protective equipment will only be effective if it fits you, and is adjusted properly. So make sure you learn how to use the PPE, and ask questions if you have any doubts about its use. You should understand why the PPE is required. Learning correct use of PPE can protect you, both on and off the job.

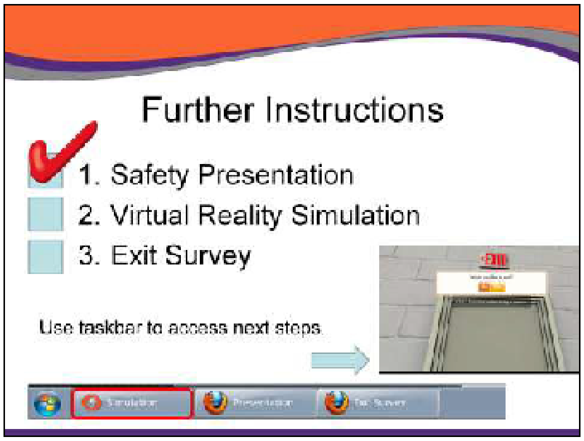
It is common practice to remind your co-workers of PPE requirements when you see they are at-risk without it.

Remember that you play an important role in preventing accidents. To be a part of a safety-culture, practice identifying violations and making changes to eliminate or to guard against these hazards. When you can't correct a hazard yourself, alert those who can, such as your supervisor.

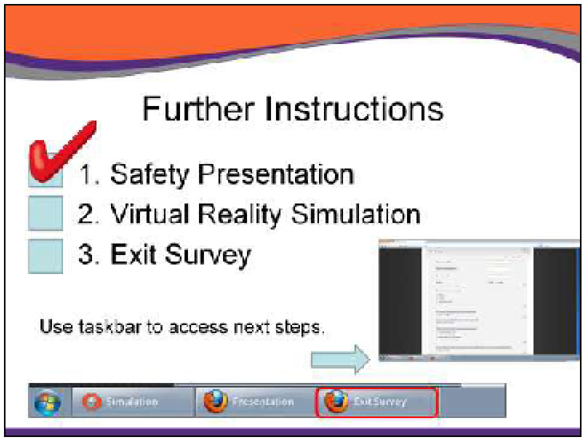
Your employer can provide you with the tools and training you need to do your job safely; but, YOU are responsible for making safe choices by following the proper safety procedure.

And don't forget to look out for your co-workers by alerting them when they are at risk.

Safety starts, with you!



You have completed the safety presentation.
There are two more activities to complete; the virtual reality simulation then the the exit survey.
To access these next two activities use the desktop taskbar located at the of your screen. Here it is enlarged.
First proceed to the virtual reality simulation by clicking the item labeled "Simulation". The simulation uses a full screen mode. This temporarily obscures the task bar while you complete the activity. Once you exit the simulation through the simulated exit doors pictured here, the taskbar will reappear.



Lastly complete the exit survey. Once you open it, the survey's first page should look like this. Along with collecting background information, the Exit Survey will ask you about your experience using the simulation. To access the Exit Survey click the taskbar item labeled "Exit Survey" shown here.
Now that you know how to access the next two activities, please begin with the simulation.

APPENDIX E: EXIT SURVEY

Confidential

Exit Survey

Please complete the survey below.

What is your participant I.D.? __________________________________

How old are you? ______________________

Are you: ☐ Male ☐ Female

How often do you use a computer?

☐ Daily
☐ Weekly
☐ Monthly
☐ A few times a year
☐ Never

Have you ever used/tested/experienced virtual reality?
(Virtual Reality is defined as a computer-generated environment of a real or imaginary place which enables a user to interact with objects in the environment.)

☐ Yes ☐ No

What is your level of video/computer game experience?

☐ None (less than 1 hour)
☐ Novice (1 to 10 hours)
☐ Intermediate (10 to 500 hours)
☐ Advanced (over 500 hours)

Have you played any video/computer games with navigational aids such as arrows/trails/paths/maps?

☐ Yes ☐ No

Have you ever had safety training in a work setting?

☐ Yes ☐ No

Highest level of education completed?

☐ Some High School
☐ High School/GED
☐ Some College
☐ Bachelor's Degree
☐ Master's Degree
☐ Advanced Graduate work or Ph.D.

Which of the following most aligns with your field of study?

☐ Architecture, Arts and Humanities
☐ Business and Behavioral Science
☐ Engineering and Science
☐ Health, Education, and Human Development

Have you ever worked in a manufacturing setting?

☐ Yes ☐ No

How did you hear about this study?

☐ Flyer
☐ E-mail
☐ word-of-mouth
☐ In class
☐ Other

If your answer to the previous question was 'Flyer', 'In Class', or 'Other', then please specify where: ______________________

Through the course of this survey you will see the term "task environment" used in some of the questions. "Task environment" refers ONLY to the virtual auto assembly plant, NOT the basic environment where the preceding practice exercises were conducted.

How much were you able to control events?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How responsive was the task environment (virtual auto assembly plant) to actions that you initiated (or performed)?

☐ NOT RESPONSIVE
☐ -
☐ MODERATELY RESPONSIVE
☐ -
☐ COMPLETELY RESPONSIVE

How natural did your interactions with the task environment seem?

☐ EXTREMELY ARTIFICIAL
☐ -
☐ BORDERLINE
☐ -
☐ COMPLETELY NATURAL

How much did the visual aspects of the task environment involve you?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How much did the auditory aspects of the task environment involve you?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How natural was the mechanism which controlled movement through the task environment?

☐ EXTREMELY ARTIFICIAL
☐ -
☐ BORDERLINE
☐ -
☐ COMPLETELY NATURAL

How compelling was your sense of objects moving through space?

☐ NOT AT ALL
☐ -
☐ MODERATELY COMPELLING
☐ -
☐ VERY COMPELLING

How much did your experiences in the task environment seem consistent with your real world experiences?

☐ NOT CONSISTENT
☐ -
☐ MODERATELY CONSISTENT
☐ -
☐ VERY CONSISTENT

Were you able to anticipate what would happen next in response to the actions that you performed?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How completely were you able to actively survey or search the task environment using vision?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How well could you identify sounds?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How well could you localize sounds?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How well could you actively survey or search the task environment using touch?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ COMPLETELY

How compelling was your sense of moving around inside the task environment?

☐ NOT COMPELLING
☐ -
☐ MODERATELY COMPELLING
☐ -
☐ VERY COMPELLING

How closely were you able to examine objects?

☐ NOT AT ALL
☐ -
☐ PRETTY CLOSELY
☐ -
☐ VERY CLOSELY

How well could you examine objects from multiple viewpoints?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ EXTENSIVELY

How well could you move or manipulate objects in the task environment?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ EXTENSIVELY

How involved were you in the task environment experience?

☐ NOT INVOLVED
☐ -
☐ MILDLY INVOLVED
☐ -
☐ COMPLETELY ENGROSSED

How much delay did you experience between your actions and expected outcomes?

☐ NO DELAYS
☐ -
☐ MODERATE DELAYS
☐ -
☐ LONG DELAYS

How quickly did you adjust to the task environment experience?

☐ NOT AT ALL
☐ -
☐ SLOWLY
☐ -
☐ LESS THAN A MINUTE

How proficient in moving and interacting with the task environment did you feel at the end of the experience?

☐ NOT PROFICIENT
☐ -
☐ MODERATELY PROFICIENT
☐ -
☐ VERY PROFICIENT

How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

☐ NOT AT ALL
☐ -
☐ MODERATELY INTERFERED
☐ -
☐ PREVENTED TASK PERFORMANCE

How much did the control devices interfere with the performance of assigned tasks or with other activities? ("control devices" refer to the mouse and keyboard)

☐ NOT AT ALL
☐ -
☐ MODERATELY INTERFERED
☐ -
☐ INTERFERED GREATLY

How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

☐ NOT AT ALL
☐ -
☐ SOMEWHAT
☐ -
☐ EXTENSIVELY

How completely were your senses engaged in this experience?

☐ NOT ENGAGED
☐ -
☐ MILDLY ENGAGED
☐ -
☐ COMPLETELY ENGAGED

How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or object?

☐ IMPOSSIBLE
☐ -
☐ MODERATE DIFFICULTY
☐ -
☐ VERY EASILY

Were there moments during the task environment experience when you felt completely focused on the task or environment?

☐ NONE
☐ -
☐ OCCASIONALLY
☐ -
☐ FREQUENTLY

How easily did you adjust to the control devices used to interact with the task environment?

☐ DIFFICULT
☐ -
☐ MODERATE
☐ -
☐ VERY EASY

Was the information provided through different senses in the task environment (e.g., vision, hearing, touch) consistent?

☐ NOT CONSISTENT
☐ -
☐ MODERATELY CONSISTENT
☐ -
☐ VERY CONSISTENT

Questions About The Task Environment

How mentally demanding was the task?

Very Low — Very High

(Place a mark on the scale above)

How physically demanding was the task?

Very Low — Very High

(Place a mark on the scale above)

How hurried or rushed was the pace of the task?

Very Low — Very High

(Place a mark on the scale above)

How successful were you in accomplishing what you were asked to do?

Perfect — Failure

(Place a mark on the scale above)

How hard did you have to work to accomplish your level of performance?

Very Low — Very High

(Place a mark on the scale above)

How insecure, discouraged, irritated, and annoyed were you?

Very Low — Very High

(Place a mark on the scale above)

The next 15 questions will reference the term 'Scale Attribute.' Scale attributes are the following 6 terms, and will be defined with each of the questions: -Mental Demand -Physical Demand -Temporal Demand -Performance -Effort -Frustration Level

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Effort How hard did you have to work [mentally and physically] to accomplish your level of performance? Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter [or yourself]? How satisfied were you with your performance in accomplishing these goals?

☐ Effort
☐ Performance

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Temporal Demand How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? Frustration How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

☐ Temporal Demand
☐ Frustration

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Temporal Demand How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? Effort How hard did you have to work [mentally and physically] to accomplish your level of performance?

☐ Temporal Demand
☐ Effort

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Physical Demand How much physical activity was required [e.g. pushing, pulling, turning, controlling, activating, etc.]? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? Frustration How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

☐ Physical Demand
☐ Frustration

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter [or yourself]? How satisfied were you with your performance in accomplishing these goals? Frustration How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

☐ Performance
☐ Frustration

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Physical Demand How much physical activity was required [e.g. pushing, pulling, turning, controlling, activating, etc.]? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? Temporal Demand How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

☐ Physical Demand
☐ Temporal Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Physical Demand How much physical activity was required [e.g. pushing, pulling, turning, controlling, activating, etc.]? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter [or yourself]? How satisfied were you with your performance in accomplishing these goals?

☐ Physical Demand
☐ Performance

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Temporal Demand How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? Mental Demand How much mental and perceptual activity was required [e.g. thinking, deciding, calculating, remembering, looking, searching, etc.]? Was the task easy or demanding, simple or complex, exacting or forgiving?

☐ Temporal Demand
☐ Mental Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Frustration How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? Effort How hard did you have to work [mentally and physically] to accomplish your level of performance?

☐ Frustration
☐ Effort

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter [or yourself]? How satisfied were you with your performance in accomplishing these goals? Mental Demand How much mental and perceptual activity was required [e.g. thinking, deciding, calculating, remembering, looking, searching, etc.]? Was the task easy or demanding, simple or complex, exacting or forgiving?

☐ Performance
☐ Mental Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Performance How successful do you think you were in accomplishing the goals of the task set by the experimenter [or yourself]? How satisfied were you with your performance in accomplishing these goals? Temporal Demand How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

☐ Performance
☐ Temporal Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Mental Demand How much mental and perceptual activity was required [e.g. thinking, deciding, calculating, remembering, looking, searching, etc.]? Was the task easy or demanding, simple or complex, exacting or forgiving? Effort How hard did you have to work [mentally and physically] to accomplish your level of performance?

☐ Mental Demand
☐ Effort

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Mental Demand How much mental and perceptual activity was required [e.g. thinking, deciding, calculating, remembering, looking, searching, etc.]? Was the task easy or demanding, simple or complex, exacting or forgiving? Physical Demand How much physical activity was required [e.g. pushing, pulling, turning, controlling, activating, etc.]? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

☐ Mental Demand
☐ Physical Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Effort How hard did you have to work [mentally and physically] to accomplish your level of performance? Physical Demand How much physical activity was required [e.g. pushing, pulling, turning, controlling, activating, etc.]? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

☐ Effort
☐ Physical Demand

Select the Scale Attribute that represents the more important contributor to workload for the specific task you performed in this experiment. Frustration How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? Mental Demand How much mental and perceptual activity was required [e.g. thinking, deciding, calculating, remembering, looking, searching, etc.]? Was the task easy or demanding, simple or complex, exacting or forgiving?

☐ Frustration
☐ Mental Demand

Additional Questions

	strongly disagree						strongly agree	N/A
Overall, I am satisfied with how easy it is to use this system.	☐	☐	☐	☐	☐	☐	☐	☐
It was simple to use this system.	☐	☐	☐	☐	☐	☐	☐	☐
I can effectively complete my work using this system.	☐	☐	☐	☐	☐	☐	☐	☐
I am able to complete my work quickly using this system.	☐	☐	☐	☐	☐	☐	☐	☐
I am able to efficiently complete my work using this system.	☐	☐	☐	☐	☐	☐	☐	☐
I feel comfortable using this system.	☐	☐	☐	☐	☐	☐	☐	☐
It was easy to learn to use this system.	☐	☐	☐	☐	☐	☐	☐	☐
I believe I became productive quickly using this system.	☐	☐	☐	☐	☐	☐	☐	☐
The system gives error messages that clearly tell me how to fix problems.	☐	☐	☐	☐	☐	☐	☐	☐
Whenever I make a mistake using the system, I recover easily and quickly.	☐	☐	☐	☐	☐	☐	☐	☐
The information (such as online help, on-screen messages, and other documentation) provided with this system is clear.	☐	☐	☐	☐	☐	☐	☐	☐
It is easy to find the information I needed.	☐	☐	☐	☐	☐	☐	☐	☐
The information provided for the system is easy to understand.	☐	☐	☐	☐	☐	☐	☐	☐
The information is effective in helping me complete the tasks and scenarios.	☐	☐	☐	☐	☐	☐	☐	☐
The organization of information on the system screens is clear.	☐	☐	☐	☐	☐	☐	☐	☐
The interface of this system is pleasant.	☐	☐	☐	☐	☐	☐	☐	☐
I like using the interface of this system.	☐	☐	☐	☐	☐	☐	☐	☐
This system has all the functions and capabilities I expect it to have.	☐	☐	☐	☐	☐	☐	☐	☐

Overall, I am satisfied with this system.	☐	☐	☐	☐	☐	☐	☐	☐

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