A Cognitive Engineering Approach for Measuring Adaptive Behavior

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Abstract

Measuring adaptive expert behavior has become an issue of interest and controversy, particularly in complex work environments where conditions can change unexpectedly. As a result, there is a need to develop a set of tools that can help assess adaptive performance and distinguish between expert and novice behavior. The purpose of this research was to develop and test measures of adaptive performance for these types of environments. In particular, the project scope was to: 1) develop and evaluate a within-trial measure for assessing adaptive performance, and 2) conduct a pilot study on operator adaptation to global changes in process time constants using DURESS II, a thermal-hydraulic microworld simulation environment. The results show that the within-trial measure developed, within-trial trajectory deviation (WTD), may be useful for assessing coupling to the work domain structure (i.e., Abstraction Hierarchy – AH). When viewing this measure across trials, the results are consistent with previously developed measures for coupling to the AH. In the pilot study, the results using previously developed measures suggest that the type of interface may affect an operator's ability to adapt to changing process dynamics. An interface designed using the physical and functional properties of the work domain tended to better support functional adaptive behavior, compared with an interface designed with a traditional approach using only physical properties of the work domain. In addition, more experienced operators were able to adapt to changing process dynamics, with a larger expertise effect in trials having large process time constants. More detailed experiments and the development of additional measures to assess adaptive performance are suggested for future research.

1. Introduction

The measurement of adaptive expert behavior has been a controversial issue among researchers. Current methods for assessing adaptive human performance are in general limited to subjective evaluations or quantitative measures that may be insensitive to adaptive factors. In addition, current methods do not adequately capture within-trial, non-linear determinants of adaptive expert performance (Hajdukiewicz, Vicente, & Eggleston, 1999). This research project investigated measurement concepts that are sensitive to expertise and adaptive behavior. The goal was to develop within- and between-trial measures that can capture variability in human-computer behavior in a manner that discriminates between novice and expert activity and variability in performance using different human-computer interfaces. These measures may then be used to study adaptive performance in the context of changing work domain dynamics and different human-computer interfaces. For example, perturbations in work domain dynamics (e.g., changing process time constants) may be more difficult for a novice to handle than an expert because the novice usually has less understanding of the inherent problem constraints at multiple levels of abstraction. Also, these perturbations may be more difficult to handle for an operator (novice or expert) who uses an interface based only on physical information, compared with an operator who uses an interface based on physical and functional information.

This project was a continuation of the work started with an initial contract, "Development of an Analytical Framework and Measurement Tools to Assess Adaptive Performance of Individual and Teams in Military Work Domains" (Hajdukiewicz et al., 1999). There were two main aspects to this follow-on project: a) the development of a within-trial measure for assessing the coupling of individuals to certain aspects of the work domain structure (i.e., level of Abstract Function), and b) an investigation of the effects of changing dynamics (i.e., process time constants) on adaptive performance as a function of human-computer interface and experience. To be manageable and include conditions that are beyond what may be representative in an actual complex work environment, the DURESS II thermal-hydraulic microworld simulation environment was used as the testbed (see Appendix A for a description).

The first two parts of the report discuss measures that may be useful for studying adaptive behavior. The first part summarizes the measures that have been used in previous research to assess adaptive performance for DURESS II. The second part builds on these set of measures with a description of a new within-trial measure, within-trial trajectory deviation, to assess the degree of coupling of the operator to some aspect of the work domain structure (e.g., level of Abstract Function), based on the analysis framework discussed in Hajdukiewicz et al. (1999). The third part of this report presents the results of pilot study on the effects of changing dynamics (i.e., process time constants) adaptive performance with two different human-computer interfaces, using the previously developed measures from the first part. The final part of the report presents some concluding remarks and directions for future research in terms of new measures and additional experiments.

2. Measuring Adaptive Behavior: Background

Preliminary analysis suggests that concepts from Cognitive Systems Engineering may provide a useful framework for motivating the design of effective measurement tools for assessing adaptive expert behavior (Hajdukiewicz et al., 1999). It has been shown, for example, that adaptive performance is correlated with low variance associated with constructs defined at an Abstract Function level of Rasmussen’s (1985) Abstraction Hierarchy (AH) when there may be simultaneously high variance in how operators use components at Physical Function level (Yu, Chow, Jamieson, Khayat, Lau, Torenvliet, Vicente, & Carter, 1997).

This section provides an overview of some of the measures of adaptive performance that were used in previous research at the Cognitive Engineering Laboratory at the University of Toronto for the DURESS II simulation environment. To be manageable, these measures were used for analyzing adaptive behavior in the pilot study on global adaptation to process dynamics, described in Section 4 of the report.

To focus the discussion, these measures are discussed in the context of DURESS II start-up trials, which are the trial pertinent to the pilot study. There are generally two parts to these types of trials. The first part, reaching the goal, involves turning on DURESS II components from a shutdown state and bringing the goal variables to their respective goal regions quickly and safely. The second part, stabilization, involves keeping the goal variables within the goal regions until steady state is achieved. As operators learn how to successfully perform this task of bringing the goal variables to the required steady state condition, they generally learn various ways to coordinate and control their actions to improve their performance. Eventually, they converge on a set of strategies that form a balance between achieving the goal quickly and stabilizing the work domain. The purpose of developing measures is to assess operators’ abilities to adapt as they are learning about the work domain and as they experience changing work situations.

The following list summarizes some of the measures that were used for assessing performance and adaptation with DURESS II from previous research. Refer to Yu, Lau, Vicente, & Carter (1998), Yu et al. (1997), and Hajdukiewicz et al. (1999) for a detailed discussion. Some of these measures were implemented into a measurement tool, ADAPT (see Yu, Khan, Lau, Vicente, & Carter, 1997).

1. <u>Task Completion Time</u>: This measure is the time required to achieve the steady state condition from an initial state (e.g., shutdown). The measure assesses an operator's performance in completing the task, but does not directly assess operator adaptation. It also cannot distinguish between an operator's ability to reach the goal and/or stabilize the goal variables, as previously outlined. However, within a set of trials, the completion times can give an indirect indication if an operator is successful at adapting to the work situation. For example, in a set of trials that have changing process dynamics, requiring different ways of adapting to the situation, low magnitude and variability in completion times provides an indirect indication that the operator has successfully adapted to these changes. In terms of expertise, the magnitude and variability of completion times tend to be higher for novices compared with experts. In the case of adapting to changing work situations once initial learning has leveled off, the magnitude and variability of completion times are lower for operators who successfully adapt to these situations (see Yu et al., 1997).
2. <u>Trajectory Variability Analysis</u>: In this set of measures, the trajectories generated in a block of trials at each level of the AH are analyzed in terms of variability. These measures provide evidence for coupling to carious layers of constraint identified by the AH, and provide evidence for adaptation as trial conditions change. Consistently low variability at the higher levels AH provides evidence for higher-order control of the work domain. Low variability at the lower levels of the AH provides evidence for low-order or proceduralized control of the work domain. These measures do not assess how well operators perform the task, but determine which level of the AH the operator is trying to control, as they gain expertise and adapt to changing work situations. The measures may be compared with trial completion time to assess how successful operators are in controlling the work domain.
3. <u>Oscillation Measures</u>: A number of measures have been developed to assess an operator's ability to stabilize the goal variables around the goal regions to achieve steady state: <u>number of oscillations</u>, <u>oscillation duration</u>, and <u>maximum deviation of oscillations from the goal state</u>. Adaptive performance and robust behavior are characterized as low values for each of these measures as trials progress and changes in work situations are introduced.
4. <u>Control Recipes</u>: This is a knowledge elicitation measure and requires each participant to write and explain how they controlled the work domain. The discussion of specific components and settings is evidence that operators may be using procedures and lower-order

control. The discussion of functional relations is evidence that operators may be engaged in higher-order control. This exercise provides evidence for coupling to the work domain that is complementary to the results from the trajectory variability analyses. When looking at this measure across trials and different levels of expertise, one may be able to see how operators adapt and cope with uncertainty as new work situations are introduced.

The measures described in this section were used in the analysis of data from the pilot study discussed in Section 4. The next section discusses a new within-trial (i.e., real-time) measure that is complementary to the measures discussed in this section. The new measure may allow the analyst to determine the extent an operator is adapting to the work situation as the trial proceeds.

3. Within-trial Measure of Coupling to Work Domain Structure

In this part of the report, we propose and evaluate a new real-time measure for assessing adaptive performance, within-trial trajectory deviation (WTD). The approach uses the AH as an analysis framework to develop a within-trial measure for operator coupling to the work domain structure. The proposed measure is based on the idea of comparing the trajectory of a target trial to the mean trajectory of a set of previous trials. The mean trajectory can change as the operators gain experience and become attuned to the interface elements and the work domain dynamics. This measure may provide evidence for determining at which level the operator is controlling DURESS II within a trial, which may in turn be useful for analyzing adaptive performance across trials.

3.1 Description

In Figure 1, a target trial is selected from the set of experiment trials. This trial is compared with the mean trajectory calculated for the last n consecutive trials, at each level of the AH. This comparison results in a calculation of the deviation between the two trajectories (refer to Section 3.2 for a detailed account of the equations).

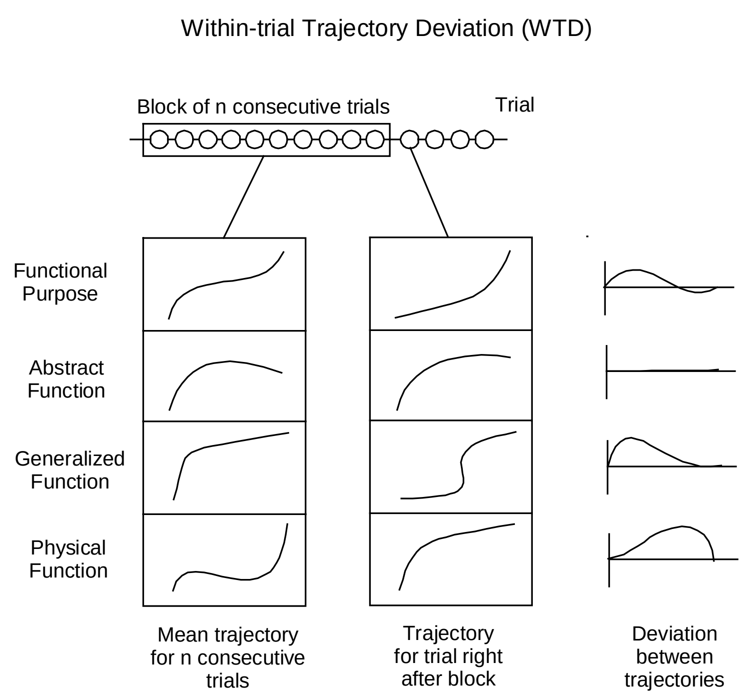

Figure 1: Within-trial measure, within-trial trajectory deviation (WTD), for assessing coupling to the AH based on deviations from generated trajectories.

Consistently small deviations provide evidence for coupling to a particular level of the AH within a trial (i.e., controlling at a lower or higher functional level) because operators use a similar trajectory with different work domain conditions (e.g., goal states). Once these deviation plots are generated, the areas under the curves may be calculated. These values can then be compared across trials. For example, consistently low deviation areas at a particular level of the AH provides evidence for a consistent coupling to the work domain structure at that level across trials.

3.2 Mathematical Formulations

This section outlines the equations used to generate this within trail measure, which was eventually implemented as a routine in ADAPT programmed in Matlab.

Suppose $\vec{x}_i$ is the output vector for target trial t, and $\vec{y}_{m\sim n}$ is the average output vector for the block of trials from *m* to *n*. In addition, *t*=*n*+1 (i.e., the target trial is right after the block of trials), 0<*m*<*n*, and {*m*, *n*, *t*} ∈ I. $\vec{y}_{m\sim n}$ is defined below:

$$\vec{y}_{m\sim n}(t) = \frac{1}{n-m+1}\sum_{i=m}^{n}\vec{x}_i(t)$$

In the WTD measure, we are interested in the trajectory deviation of a trial (trial number *t*) from the mean trajectory of its proceeding block of *v* trials (where *v*=*n*-*m*+1).

$$\text{WTD} = \Delta_t(t) = |\vec{x}_t(t) - \vec{y}_{(t-v)\sim(t-1)}(t)|$$

Note that since the duration is different from trial to trial, we count the time from 0 to *ltime* seconds, which is less than the time duration of most trials. Currently it is 300 seconds since for most of trials, the work domain is pretty stable after 300 seconds. It is changeable via function adapt.m in ADAPT.

Also note that in the calculation, we used a sample period of 3 seconds, this is acceptable considering the time constants used in the longitudinal study with DURESS II (i.e., time constant is 5s for pumps and valves, 15s for heaters) (Christoffersen, Hunter, & Vicente, 1996).

$\Delta_i(t)$ (i.e., WTD) is plotted versus time (from 0 to *ltime* seconds), as shown in Figure 2. This shows the deviation of this trial from the mean trajectory of its preceding block of trials.

The area under the deviation curve in Figure 2 can be used as an across trial measure (AD). It is defined as:

$$z_i = \int_{t=0}^{t=ltime} |\Delta_i(t)|dt$$

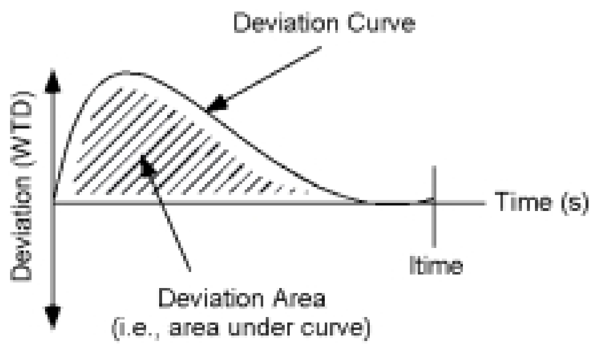

Figure 2: Within-trial trajectory deviation (WTD) plotted against time for a trial.

A graph is generated for the area under the deviation curve across trials, which can indicate adaptive performance if deviations areas are consistently low at particular levels of the AH as work domain conditions change.

3.2.1 <u>Deviation of Trajectories at Level of Function Purpose:</u>

At this level of the AH, the output is a vector consisting of the following four variables:

- water outflow of upper reservoir normalized by its goal value
- water outflow of lower reservoir normalized by its goal value
- water temperature of upper reservoir normalized by its goal value
- water temperature of lower reservoir normalized by its goal value

3.2.2 <u>Deviation of Trajectories at Abstract Function Level:</u>

At this level of abstraction, the output vector consists of fourteen components.

- mass level of upper reservoir
- mass inflow of upper reservoir normalized by the goal value of mass demand
- mass outflow of upper reservoir normalized by the goal value of mass demand
- energy inflow from water of upper reservoir normalized by the goal values of mass demand, temperature and scale

- energy inflow from heater of upper reservoir normalized by the goal values of mass demand, temperature and scale
- energy outflow normalized of upper reservoir by the goal values of mass demand, temperature and scale
- energy level normalized of upper reservoir by the goal values of mass demand, temperature and scale
- mass level of lower reservoir
- mass inflow of lower reservoir normalized by the goal value of mass demand
- mass outflow normalized of lower reservoir by the goal value of mass demand
- energy inflow from water of lower reservoir normalized by the goal values of mass demand, temperature and scale
- energy inflow from heater of lower reservoir normalized by the goal values of mass demand, temperature and scale
- energy outflow normalized of lower reservoir by the goal values of mass demand, temperature and scale
- energy level normalized of lower reservoir by the goal values of mass demand, temperature and scale

3.2.3 Deviation of Trajectories at Flow Level

At this abstraction level, the output vector consists of ten variables.

- FVA flow normalized by full scale
- FVA1 flow normalized by full scale
- FVA2 flow normalized by full scale
- FVB flow normalized by full scale
- FVB1 flow normalized by full scale
- FVB2 flow normalized by full scale
- FHTR1 flow normalized by full scale
- FHTR2 flow normalized by full scale
- water outflow of upper reservoir normalized by full scale
- water outflow of lower reservoir normalized by full scale
-

3.2.4 Deviation of Trajectories at Action Level

At this abstraction level, the output vector consists of twelve components.

- PA state
- PB state
- VA setting normalized by full scale
- VA1 setting normalized by full scale
- VA2 setting normalized by full scale
- VB setting normalized by full scale
- VB1 setting normalized by full scale
- VB2 setting normalized by full scale
- HTR1 setting normalized by full scale
- HTR2 setting normalized by full scale
- water outflow of lower reservoir normalized by scale
- water outflow of upper reservoir normalized by scale

3.3 Application of Measures to Data from Previous Research

The trajectory deviation measures (i.e., WTD and AD) were implemented in Matlab and applied to previous research data on longitudinal adaptation in complex work domains (see Christoffersen et al., 1996; Yu et al., 1997). The results are shown in Figures 3 through 5. Figure 3 shows the deviation curves within a trial (i.e., WTD) for all levels of the AH (i.e., trial 211) for the best participants in terms of trial completion time for each interface group (i.e., AV for P+F interface, and TL for P interface). A block size of 40 trials was selected in the calculation of the mean trajectory (i.e., trials 171-210). Figure 4 shows the change in deviation areas (i.e., AD) for these participants for trials 41-220, using the 40 previous trials to calculate the mean trajectory. The calculation of ADs started at trial 41 because of the selected block size of 40 trials (Note: trial block sizes ranging from 30-50 had no qualitatively noticeable difference in AD plots). Figure 5 displays the average deviation areas for each block of 40 trials (four blocks from trial 61-220) for these participants.

Some of the observations from applying this new measure are noted below.

1. In Figure 3, AV and TL had low deviation values at the level of Functional Purpose. In addition, AV had lower deviation values at the level of Abstract Function and higher deviation values at the levels of Generalized Function and Physical Function, compared with TL. This suggests that for trial 211, AV was more coupled to level of Abstract Function and less coupled to the lower levels of abstraction, compared with TL.

2. In Figures 4 and 5, the deviation areas show that AV and TL roughly had similar low values at the level of Functional Purpose. Comparing the last 40 trials in a t-Test, there is no significant difference between the means (p=0.40, one-tail, df=63). At the level of Abstract Function, AV had significantly lower values for deviation areas, compared with TL difference (p<0.01, one-tail, df= 35). At the level of Generalized Function, there was no significant difference between AV and TL (p=0.40, one-tail, df=58). Finally, at the level of Physical Function AV had significantly higher values of deviation areas, compared with TL (p<0.1, one-tail, df=53).
3. When comparing the deviation areas across a block of trials, the results are consistent with the results in Yu et al. (1997) from the analysis of trajectory variances (i.e., AV was coupled to higher levels of abstraction and TL was coupled to lower levels of abstraction).

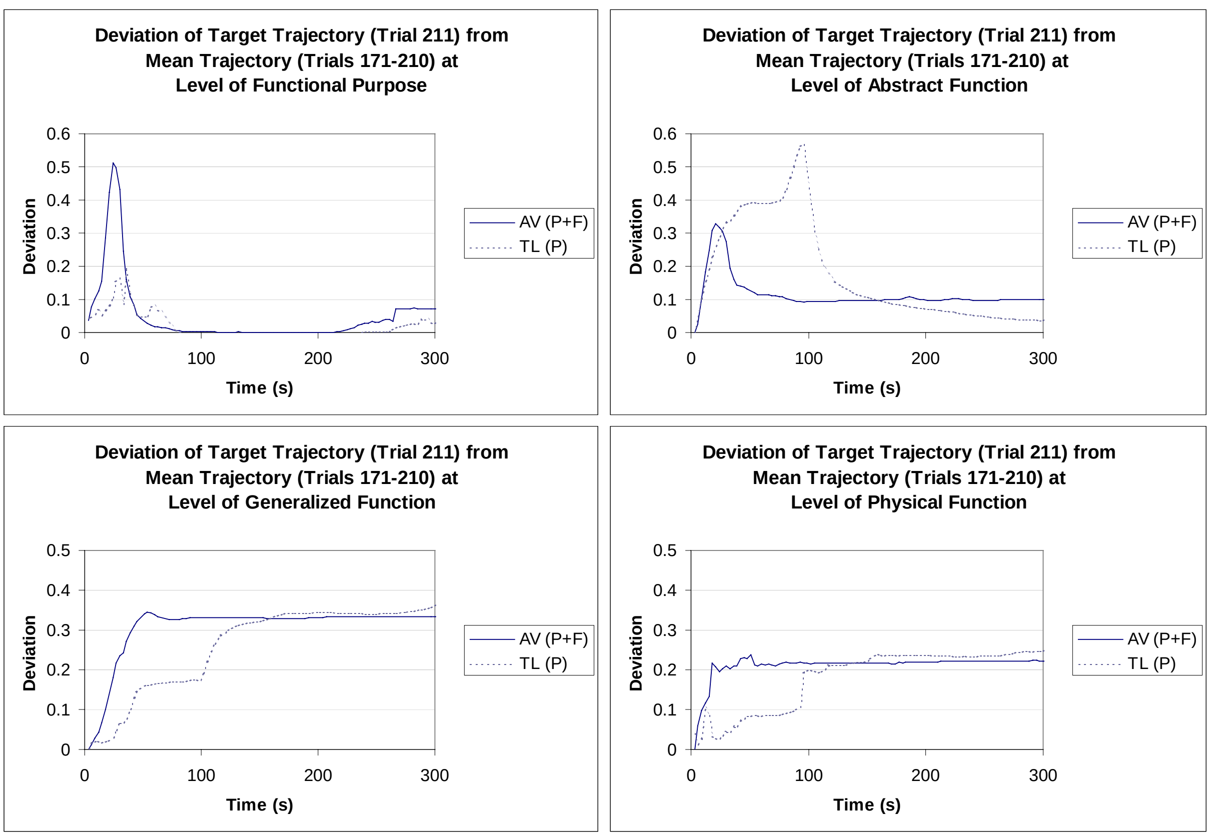

Figure 3: Deviation of target trajectory (trial 211) from mean trajectory (calculated from trials 171-210) for best participant in each interface group.

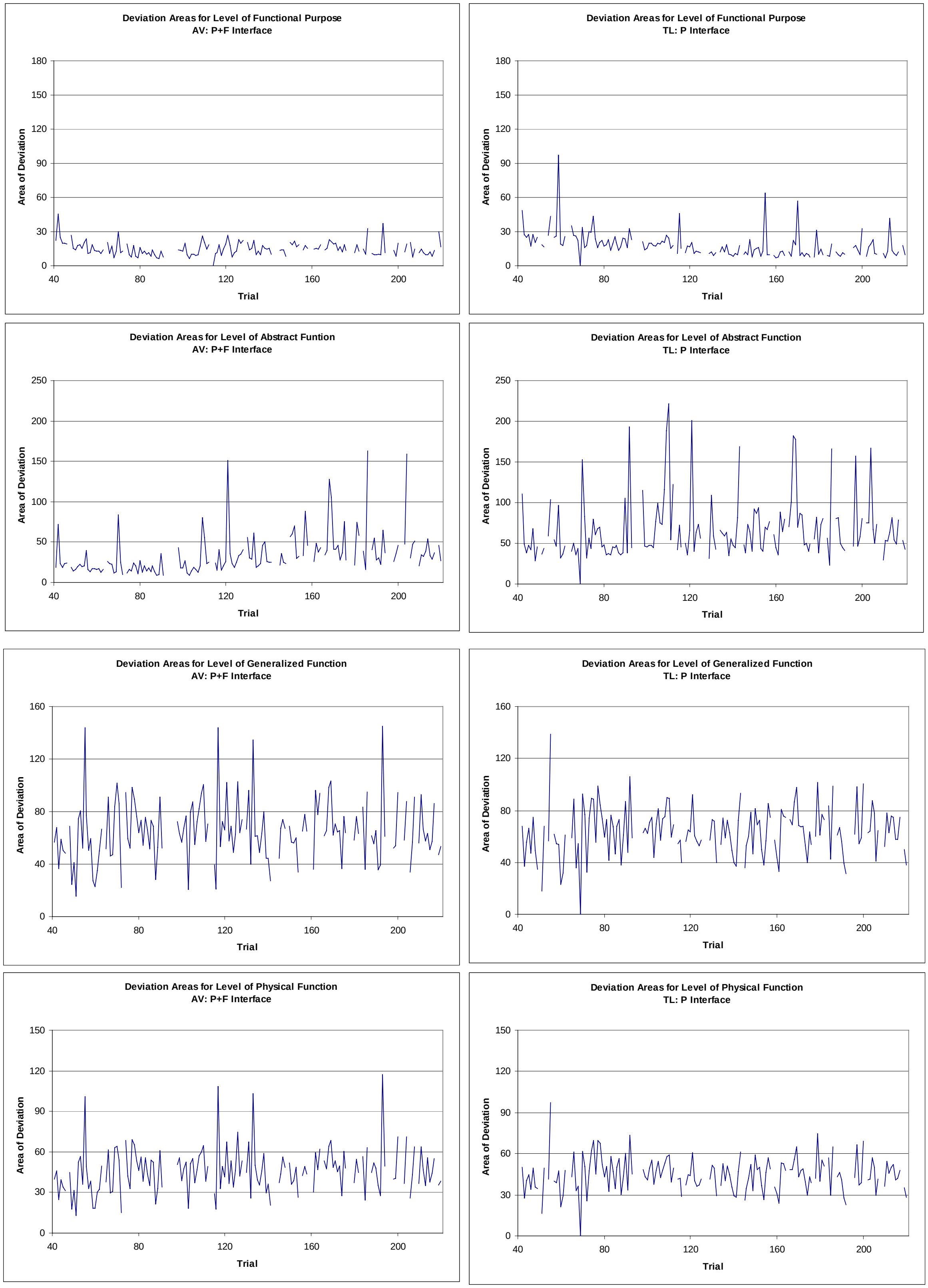

Figure 4: Deviation areas for each level of abstraction calculated from trials 41-220 for best participants in each interface group (40 trials used to calculate the mean trajectory).

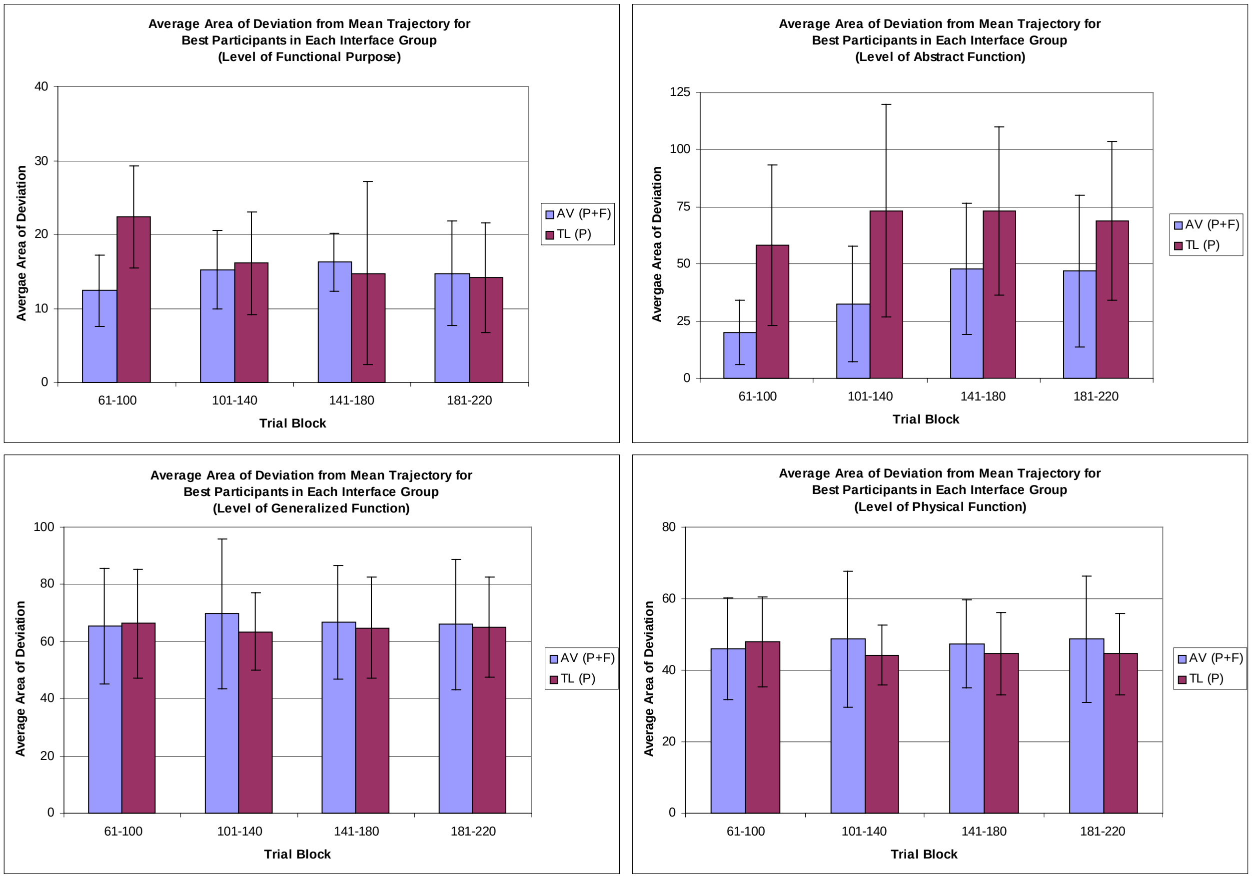

Figure 5: Average deviation areas for best participants in each interface group for 4 blocks of 40 trials from 61-220.

The WTD measure introduced in this section provides a basis for measuring coupling to the AH within a trial. It may provide insight into how consistent this coupling is as trials progress (i.e., provides a real-time measure), and how often operators deviate from particular trajectories in controlling the work domain and exploring various strategies. As different conditions are introduced in the work domain, the WTD measure may be able to assess if a operator is trying to adapt to keep the deviation low at a particular level of abstration.

As mentioned in point 3, when using this measure across trials by calculating the ADs, the results are similar to those found in Yu et al. (1997) with the analysis of trajectory variances. The main difference between the measures is that this measure provides more detail in terms of identifying specific trials where trajectories deviate from a mean trajectory. The trajectory variability analysis measures the variance across a block of trials, not specific to any one trial.

The main similarity between the measures is that consistently higher deviation values from a mean trajectory correspond with high variances across a block of trials.

In the next section, we demonstrate how the measures described in Section 2 can be used in an experiment on adaptation to changing process dynamics. In particular, the operators' abilities to adapt to changing process dynamics, as they gain experience using two different interfaces, will be assessed.

4. Pilot Study of Adaptation to Process Dynamics

The purpose of this pilot study was to investigate the effect of different human-computer interfaces and expertise to global changes in work domain dynamics (i.e., process time constants). DURESS II, a microworld simulation environment of a thermal-hydraulic process control system, was used as the testbed for this experiment (see Appendix A for a detailed description) (Vicente, 1999). Participants were randomly assigned to two interface groups. The first group used the P interface (displaying predominantly physical information), based on a process and instrumentation diagram of DURESS II. The second group used the P+F interface (displaying physical and functional information), based on an AH analysis of DURESS II. Participants in both groups controlled DURESS II under normal conditions and in conditions where the process time constants were perturbed to varying degrees. The effect of experience was also assessed by comparing performance in earlier trials with later trials in the experiment. Performance was assessed using the previously developed measures as discussed in section 2.

4.1 Method

4.1.1 Pilot Study Design

The pilot study was conducted using 4 participants (2X2 between-subjects design). Participants were first assessed and selected based on technical expertise and cognitive style (see Section 4.1.2). Each selected participant was given a brief tutorial and evaluated on the DURESS II environment (i.e., the names, locations, and interconnections of components). The experiment trials were divided into two consecutive phases: learning and manipulation phases. In the learning phase, participants continuously become proficient at operating DURESS II, with changing goal states and a few manipulations to test less experienced behavior. This phase lasted for 60 trials, because around this point the learning effect has been shown to approximately flatten out (based on previous studies with DURESS II – Yu, Torenvliet, & Vicente, 1998). In the manipulation phase, changes to the process time constants of all DURESS II components were randomly introduced by a specific factor from a reference configuration (manipulation factors = 0.1, 0.5, 1, 2.5, 5, 7.5, 10). For this study, the reference configuration consisted of pumps/valves with time constants of 5s each, and heaters with 15s each. As an example, a manipulation factor of 0.1 had the time constants of 0.5s and 1.5s for pumps/valves and heaters, respectively. This phase lasted for 20 trials.

A number of experiment controls were introduced to minimize confounding effects. In general, process parameters (e.g., process capacities, fluid properties, simulation tasks) and display features (e.g., location of components, scales) were held constant. The flow demand goal states were randomly assigned for each trial, for a block of 20 trials. The flow demand goal states were balanced based on strategy opportunities for feedwater system (FWS) configurations (i.e., 6 single FWS, 7 decoupled FWS, and 7 full FWS) (refer to Vicente, 1999 for a detailed explanation). There were four identical blocks (i.e., same order with respect to goal states) of 20 trials for this experiment (first 3 blocks = learning phase, last block = manipulation phase) (Figure 6). Refer to Appendix B for a list of trials with goal states and time constant values for each component.

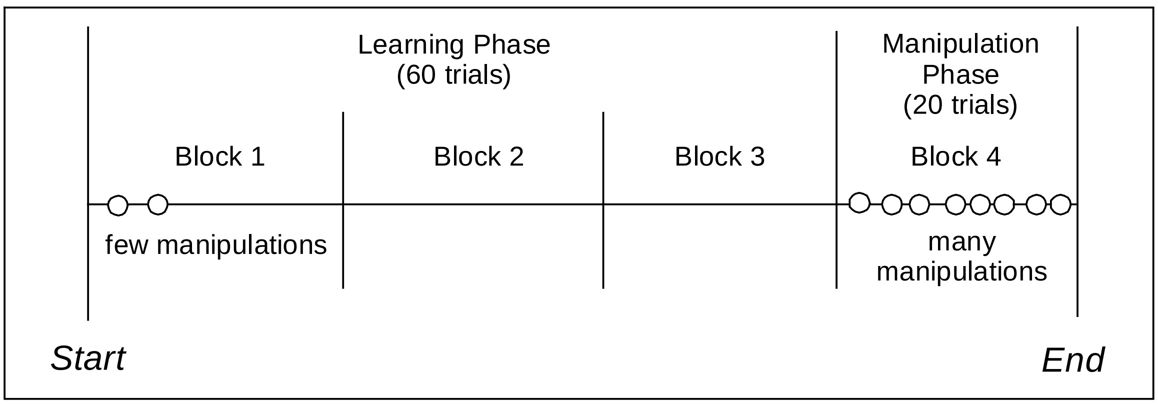

Figure 6: Overview of pilot study (circles represent manipulation trials).

4.1.2 <u>Participants</u>

The participants selected for this experiment were university engineering students, contacted by local advertisement. They were selected based on their willingness to participate, their acquaintance with comparable computer work domains, the degree to which they possessed an understanding of the principles governing the behavior of DURESS II (i.e., similar technical background in fluid mechanics and thermodynamics (1-2 university level courses and limited industry experience)), and their cognitive style (refer to Appendix C and Howie, 1995 for an explanation of how cognitive style was assessed). Each participant was paid at a standard rate ($10/session based on attendance and performance; each session was approximately 1 hour). Participants were required to sign a consent form and were fully debriefed about the experiment. All data remained confidential and no participant was identified individually. They were allowed to withdraw from the experiment at any time, if so they so desired, and would be paid for the time they invested up until that point. No participants withdrew from the pilot study.

4.1.3 Apparatus and Data Collection

Throughout the experiment, the participants used the DURESS II microworld simulation environment, with either the P or P+F interface (see Appendix A). This simulation was programmed on an SGI machine with an IRIX operating work domain. The participants received information about the state of the process by viewing a high-resolution, colour graphics display presented on a computer screen. They were entering trial parameters using a standard computer keyboard and controlling this interactive, dynamic simulation using a mouse.

Data were collected from a number of sources, most of which were unobtrusive and recorded on-line by the computer as the participant performed the task. First, a questionnaire was administered to capture demographic data at the beginning of the experiment. Second, all work domain state information was recorded by the computer, triggered by operator actions on the human-computer interface. Third, at certain intervals (i.e., before trials started, and after the 60^{th} and 80^{th} trials), participants performed an exercise designed to capture how they controlled the work domain (i.e., control recipes – refer to Yu et al., 1997 for a detailed explanation). Fourth, the investigator was taking notes during the experiment to capture some comments from each participant (however, participants were not instructed to talk about their actions during the experiment). Finally, a debriefing session occurred at the end of the experiment for each participant to capture retrospective comments regarding the strategies used, general opinions of the interface, and effect of changing time constants on the trials (captured through audio recordings). At this time, the investigator answered any final questions.

4.1.4 Procedure

The following procedure was performed for the pilot study (Appendix C contains the relevant documentation for the experiment):

1. Each participant read an explanation of the purposes of the experiment and what they would expect (Appendix C1). The investigator answered some questions the participants had. Also, participants were asked to fill out a consent form and initial questionnaire providing demographic and technical background information (Appendix C2). Each

participant was named after a Formula One racecar driver for anonymity (Franchitti, Andretti, Moore, and Tracy).

2. In the introduction session, the spy ring history exercise and analysis was conducted for each participant (test was approximately 1.5-2 hrs/participant) – Appendix C3. This exercise assesses a participant's cognitive style in problem solving (Howie, 1995). After conducting the test, three scores are calculated (holist, serialist, and neutral). Participants were selected and matched based on similar cognitive style test scores and profiles (i.e., combination of three scores). Two pairs were selected for this pilot study (Group 1: Franchitti and Andretti; Group 2: Tracy and Moore). Matched participants were randomly assigned to an interface (P+F interface: Franchitti and Tracy; P interface Andretti and Moore).
3. In the first trial session, each participant was reminded of the purposes of the experiment (Appendix C4) and was given a tutorial on the components of DURESS II (independent of the interface). After completing the tutorial, the participants were given a brief test (refer to the first part of Appendix C5). Next, each participant was introduced to a specific interface (P or P+F), discussing only what the elements were, not the functioning of the work domain (refer to the last part of Appendix C5).
4. Participants conducted the experiment trials (60 learning, 20 manipulation). Refer to Appendix B for the list of trials. After some trials, participants were asked for general comments regarding the trial. The investigator took notes during and between trials regarding participant actions and comments.
5. Before the trials started, and after the 60th and 80th trials, participants were asked to write out a control recipe, outlining a description of how they controlled DURESS II (see Appendix C6 for the instruction sheet). The purpose for
6. At the end of the experiment, there was a debriefing for each participant with the purpose of capturing their comments on how they controlled the work domain and what effect the manipulations had on their actions, strategies, and performance.
7. The data were analyzed using the measures outlined in Section 2.

4.2 Results

From the pilot study, a number of interesting observations were noted. In this section, we describe the findings in terms of the measures discussed in Section 2.

4.2.1 Trial Completion Time

Trial completion time in the pilot study was defined as the time to reach a steady state condition (i.e., output demand and temperature variables within their respective goal regions for a period of 5 minutes) starting from a shutdown state (i.e., all pumps, values, and heaters were off, and the reservoirs were empty). Trial completion times are shown below in Figure 7 for each participant, and average values for each block of 20 trials are shown in Figure 8.

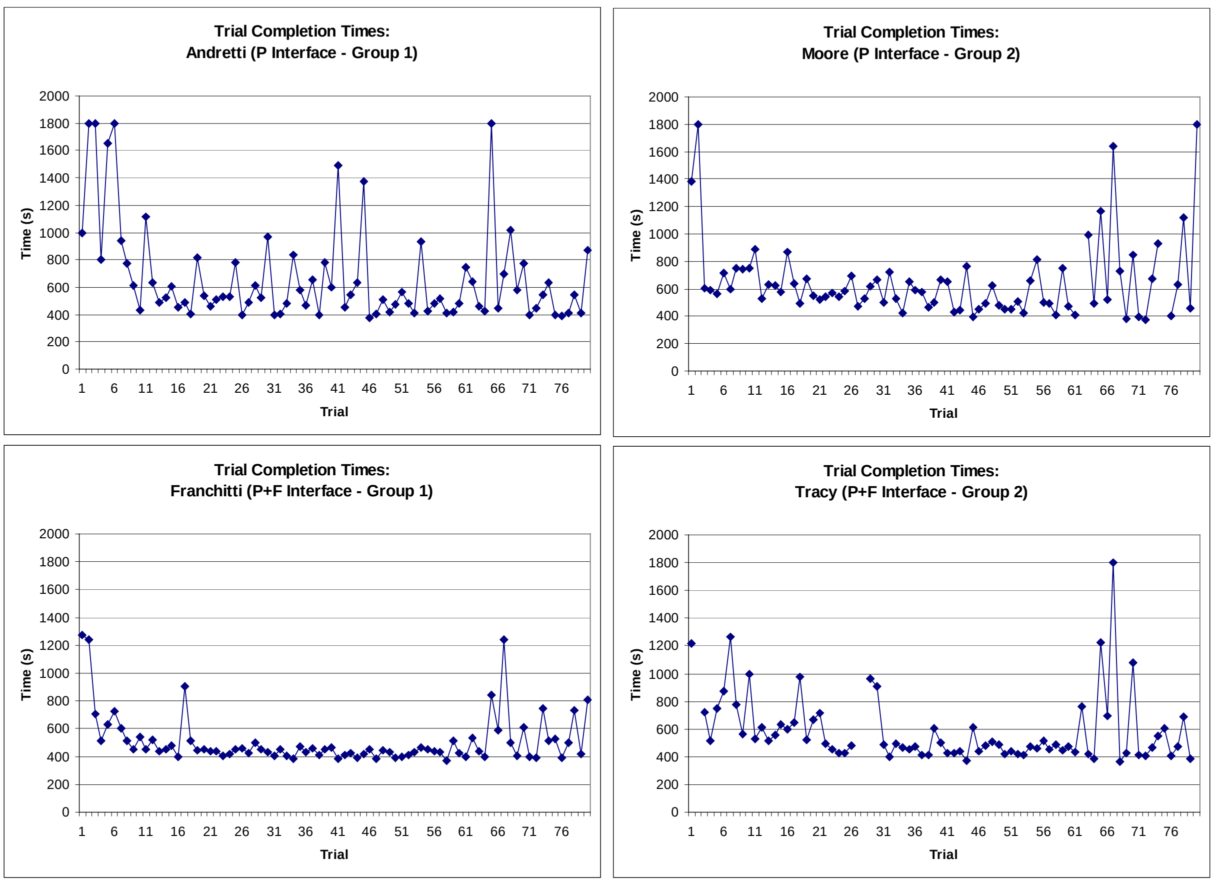

Figure 7: Trial completion times for each participant in the pilot study.

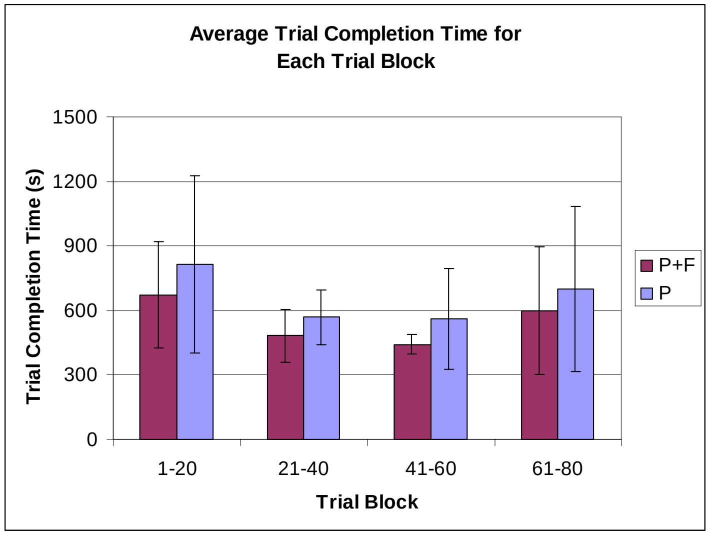

Figure 8: Average trial completion time for each trial block (20 trials).
(Error bar = 1 standard deviation).

From Figures 7 and 8, as the learning phase progressed (i.e., trials 1-60), both P and P+F participants had improved (i.e., faster) trial completion times on average. During the manipulation phase (i.e., trials 61-80), both interface groups experienced slower and more varied completion times compared with the last block of the learning phase (i.e., trials 41-60). Overall, the completion times for P participants were generally slower and more varied, compared with P+F participants for both the learning and manipulation phases (across trials within-subjects and within trials between-subjects).

Another way to look at this data is to graph the distribution of completion times across a block of 20 trials (i.e., number of completion times that are within a particular range of values). This is shown in Figure 9a and 9b. When comparing each block of 20 trials, the distribution of completion times tends to be flatter and spread out for P participants, and sharper and focused for P+F participants. These findings are similar to those found in Christoffersen et al. (1996).

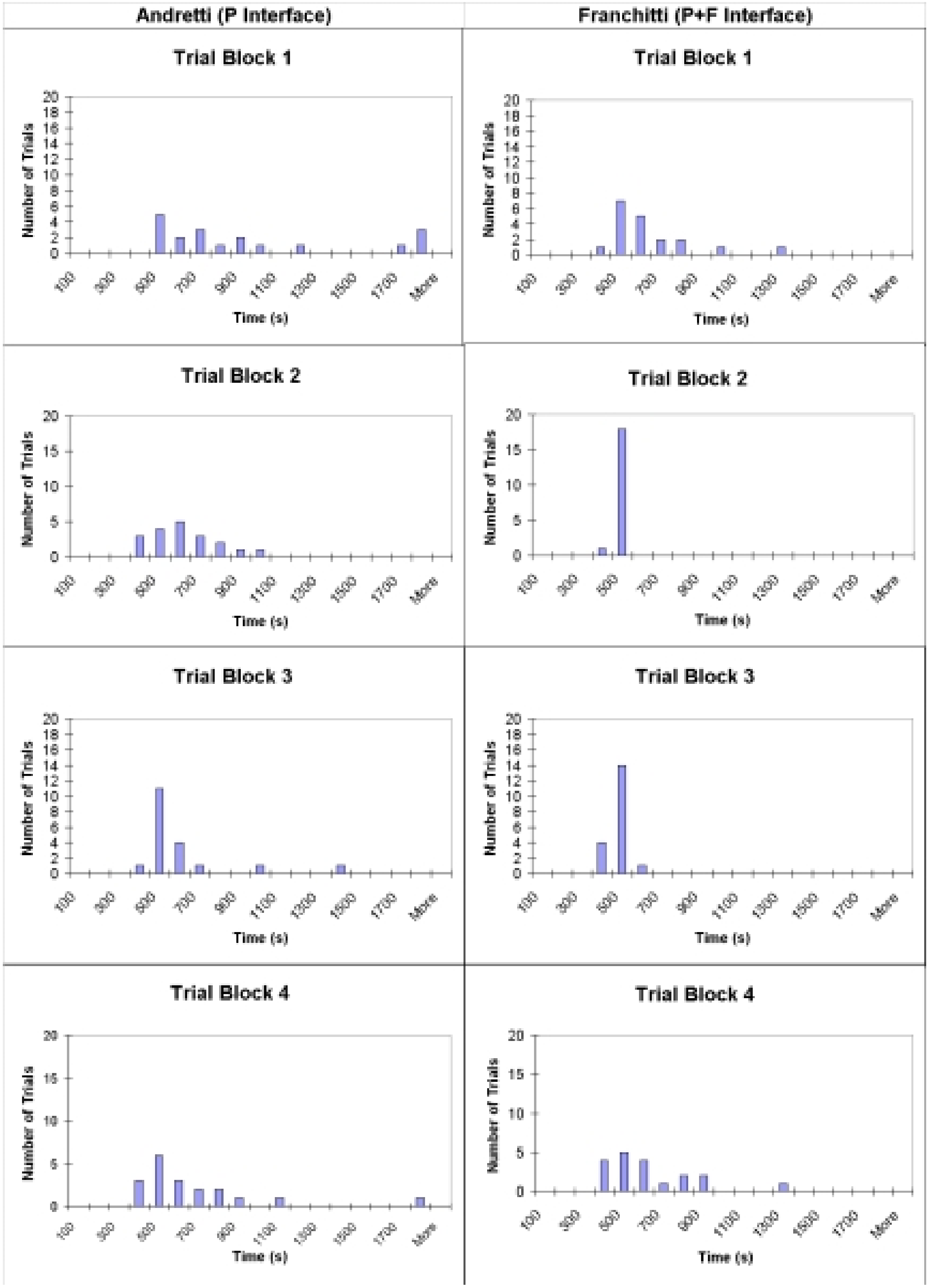

Figure 9a: Distribution of completion times for Group 1 participants.

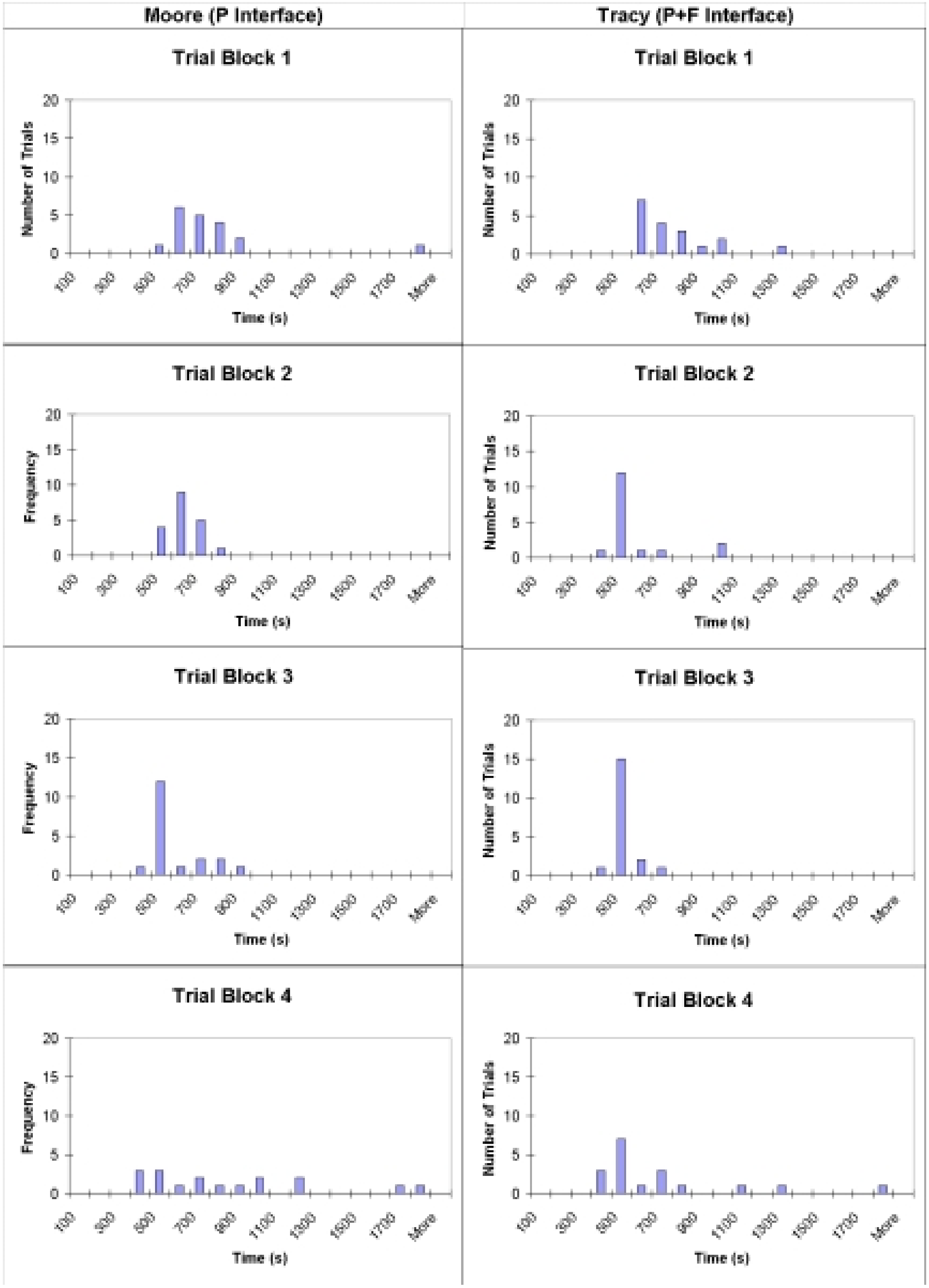

Figure 9b: Distribution of completion times for Group 2 participants.

Within the manipulation phase, completion times can be compared with manipulation factors (i.e., the factor that time constants are multiplied from the reference value). Figure 10 plots all trials in the last block against the manipulation factor. Figure 11 plots these trials according to the order they were presented in the block.

During the manipulation trials, trial completion times varied according to the process time constant factor from the reference configuration (Figures 10 and 11). In general, P participants had slower completion times and more varied distributions across process time constant factors, compared with P+F participants. In addition, completion times for the reference configuration (i.e., 1) were more varied for P participants compared with P+F participants (Figure 11).

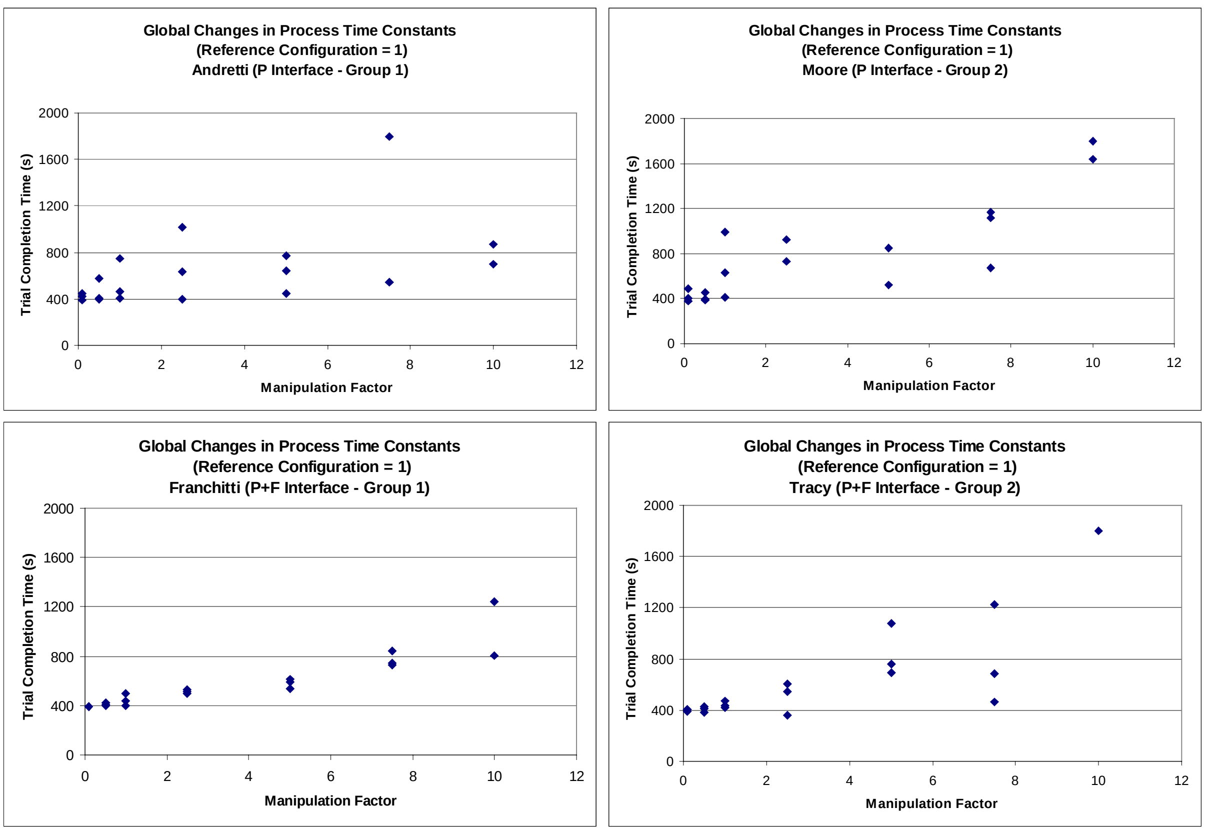

Figure 10: Trial completion time as a function of manipulation factor.

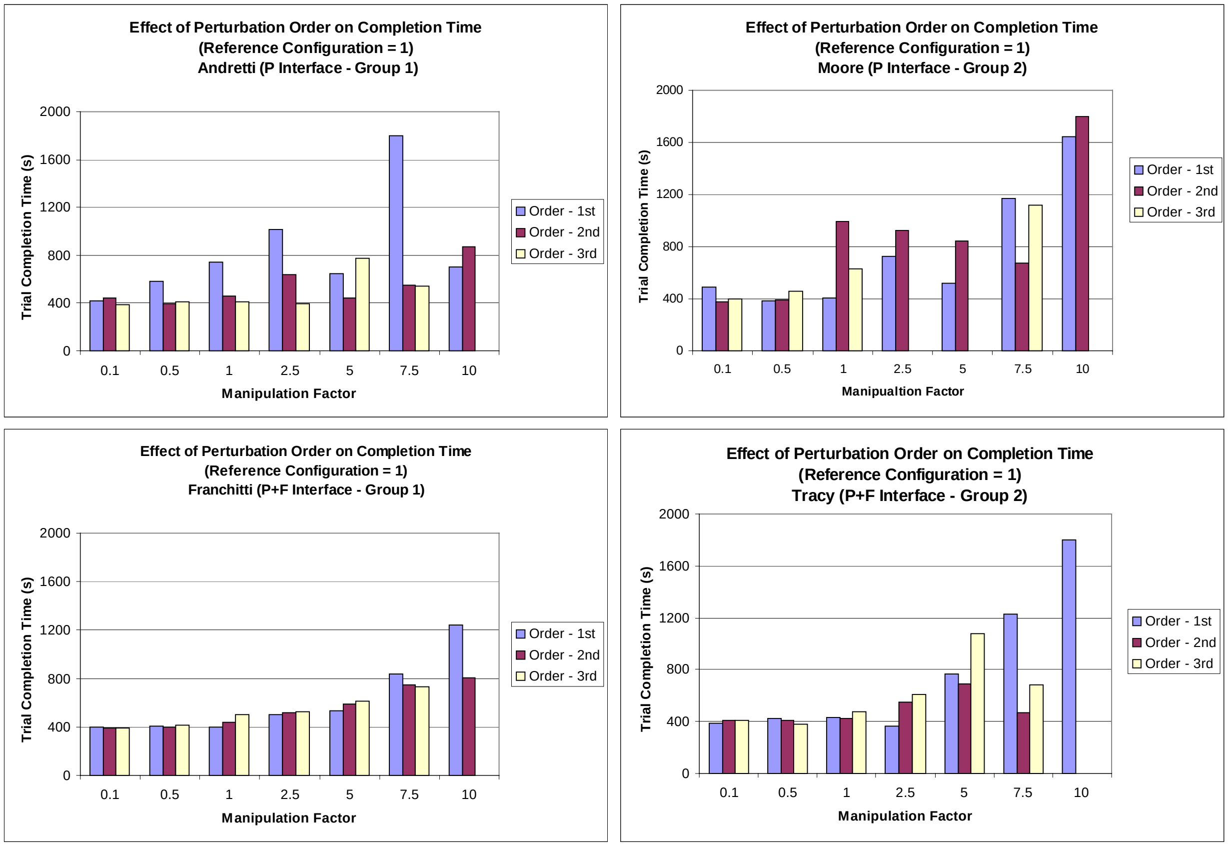

Figure 11: Effect of perturbation order on trial completion time.

The effect of experience in adapting to manipulations may be examined by comparing early trials (i.e., first block) with late trials (i.e., fourth block). This is shown in Figure 12 for manipulation factors of 5X and 0.1X. For the manipulation factor of 5X, Andretti (P interface) did not complete the early trial (i.e., simulation timed out at 30 minutes). Moore (P interface) did not complete both trials (i.e., early trial timed out at 30 minutes, late trial resulted in a reservoir overflowing). Franchitti (P+F interface) completed both trials. Tracy (P+F interface) did not complete the early trial (i.e., pump blew up). For the manipulation factor of 0.1X, all participants completed both trials (i.e., early and late).

For most cases, there was a general improvement for late trials compared with early trials in terms of completion times. The higher process time constant (i.e., manipulation factor = 5) had a larger percentage improvement compared with the lower time constant (i.e., manipulation factor = 0.1).

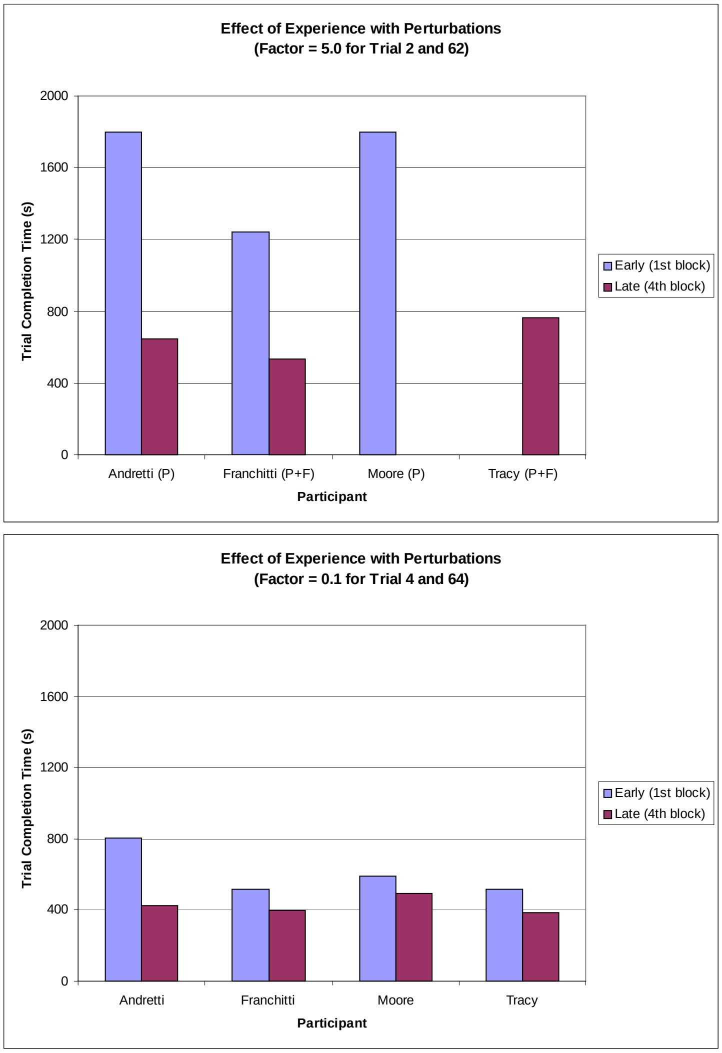

Figure 12: Effect of experience on perturbations.

4.2.2 Trajectory Variability Analyses

In these analyses, the variability of trajectories generated at each level of abstraction is presented for 4 blocks of 20 trials each. The average variability was calculated for each interface group (Figure 13). On average, P+F participants had lower variability and P participants had higher variability in the trajectories of higher-order variables of the AH (i.e., level of Abstract Function). In addition, P participants had lower variability and P+F participants had higher variability in the trajectories of lower-order variables of the AH (i.e., level of Physical Function). These findings replicate what was found in previous studies (i.e., Yu et al., 1998).

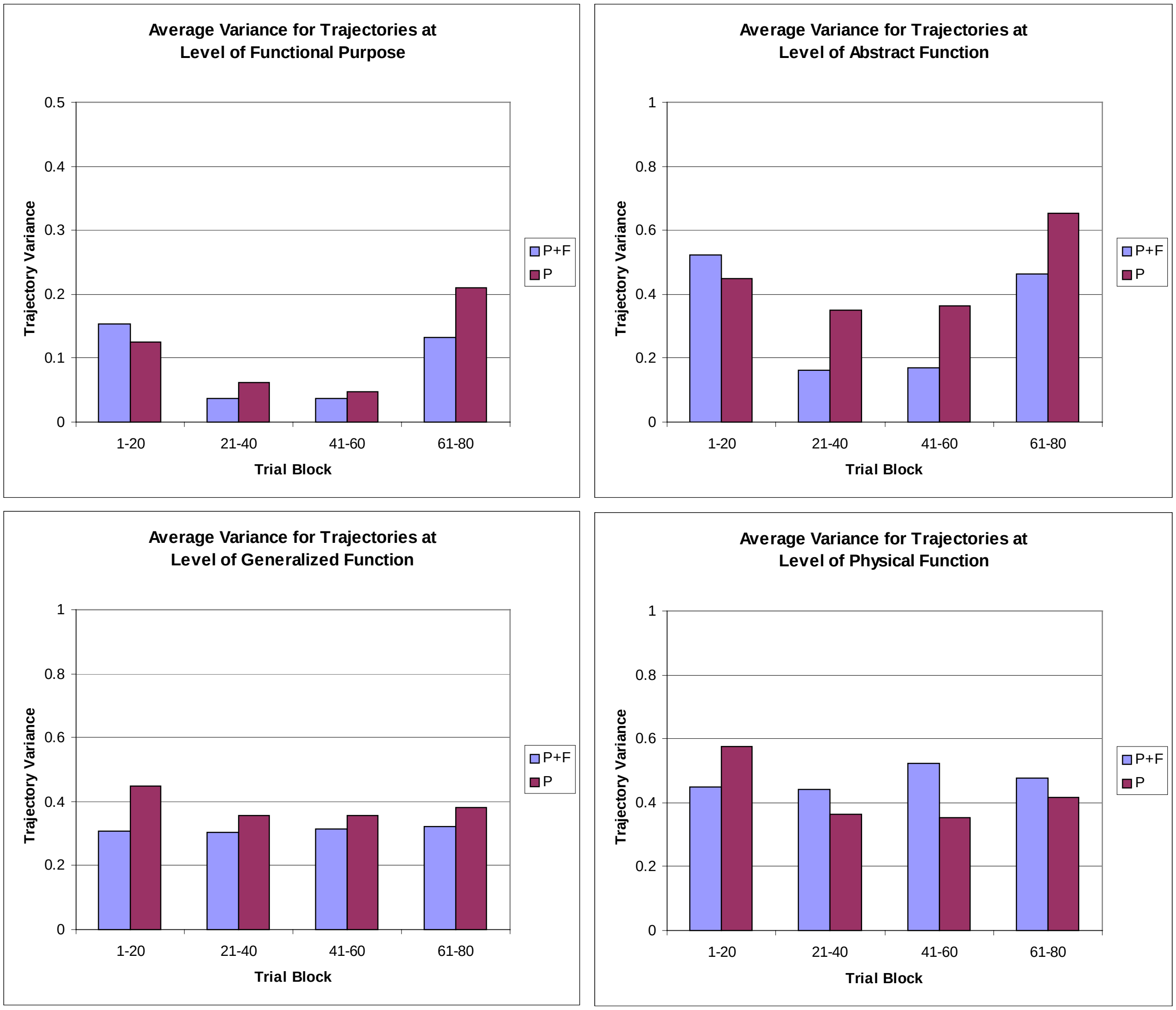

Figure 13: Average variance for trajectories at each level of abstraction for each interface group.

4.2.3 Control Recipes

Control recipes were analyzed for each participant as the pilot study progressed. Just before the manipulation phase, P participants generally used a particular procedure for acting on components in DURESS II. P+F participants focused primarily on controlling higher-order variables (i.e., mass and energy relations), and adjusted actions on components based on the context. This pattern continued for both P and P+F participants in the manipulation phase, except that some participants (i.e., P+F interface: Franchitti, Tracy; and P interface: Moore) tried to adjust their strategies for controlling the work domain based on the manipulation factor. Andretti used the same strategy throughout the manipulation phase.

4.2.4 Oscillation Measures

The trajectories of the goal variables were analyzed in terms of oscillation characteristics. In particular, the number of oscillations, duration of oscillations, and maximum deviation of oscillations were studied. Figure 14 show the average values of these measures for 4 blocks of 20 trials for each interface group.

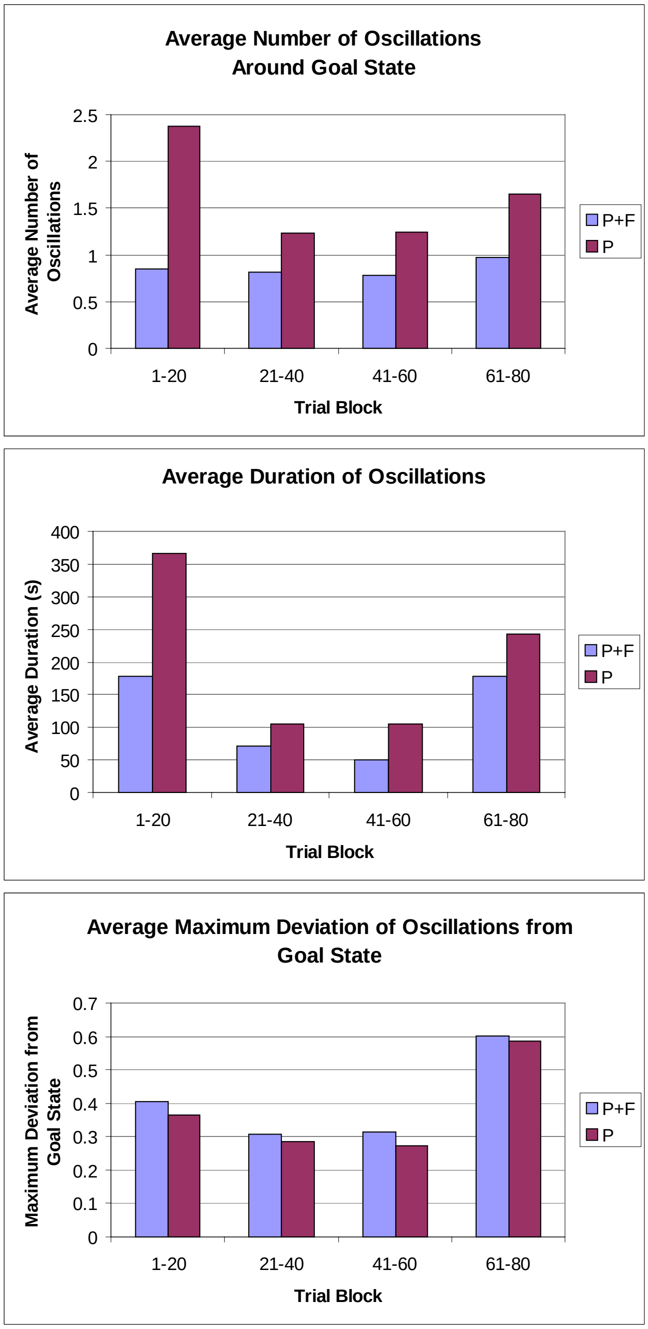

Figure 14: Oscillation characteristics of the goal variables for each interface group.

On average, P participants had more oscillations, longer oscillation durations, and lower maximum deviations of oscillations in achieving the goal state compared with P+F participants.

* * * * *

The results from the pilot study suggest that the type of human-computer interface does affect the ability of operators to adapt to changing process dynamics. In particular, the P+F interface tends to support more robust control of the work domain to global changes in process time constants, compared with the P interface. However, since this is a pilot study with only 4 participants, additional experiments are required to make any conclusions regarding the effects.

5. Conclusions

The purposes of this project were to develop a within-trial measure to assess coupling to the AH and to conduct a pilot study on adaptation to global changes in process time constants for DURESS II.

The within-trial measure, trajectory deviation, provides a new way of looking at coupling to the AH that is complementary to the insights provided by previous measures (i.e., trajectory variability analyses). The measure is useful because it is a method for assessing operator coupling to the AH as a trial proceeds, by looking at deviations between a target trial and the mean trajectory of previous trials. When comparing these deviations across trials, the results are similar to results found with trajectory variability analyses.

The pilot study shows evidence that the type of human-computer interface does affect the ability of operators to adapt to global changes in process time constants. Comparing the two human-computer interfaces used in the experiment, the P+F interface (designed using the principles of EID) tends to better support adaptation to the mentioned changes, compared with the P interface (designed using the principles of mimic displays). There was also evidence that experience using the difference interfaces did affect adaptive performance. More experienced operators were better able to adapt to the changes in process dynamics, compared with novices. However, it is important to note that these results are preliminary. A detailed experiment involving more participants is required to determine if any conclusions can be made.

In order to continue with this line of research, future work is proposed. These proposed activities fall under two general categories: experiments on adaptation to changing process dynamics and development of new measures to assess adaptive performance. In terms of experiments, a continuation of the pilot study with a detailed experiment on adaptation to global changes in process dynamics is required to assess the validity and reliability of the preliminary results described in this report. Also, measures presented in this report may be further assessed with a number of additional experiments: a) adaptation to local changes in process dynamics, b) adaptation to changing component capacities (symmetrically and asymmetrically), and c) adaptation to changes in interface forms. In terms of new measures, directions that are proposed include developing a measures of coupling between levels of the AH and coupling between action and work domain state at various levels of the AH, both within a trial and across trials.

6. Acknowledgements

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Appendix A: DURESS II Microworld Simulation Environment

DURESS II is a microworld simulation environment of a process control work domain that has been used for studying adaptation in complex work domains and assess operator performance to different design interventions (Yu, Lau, Vicente, & Carter, 1998; Vicente & Rasmussen, 1990). The physical structure of DURESS II is shown in Figure A1. DURESS II consists of two feedwater work domains, which supply water to two reservoirs. The operator has control over eight valves (six input valves: VA, VB, VA1, VA2, VB1, VB2, and two output valves: VO1 and VO2), two pumps (PA and PB), and two heaters (HTR1 and HTR2). The operator is required to achieve the dual goals of satisfying external, dynamic demands for water (MO1 and MO2) while also maintaining each of the reservoirs at their respective temperature setpoints (T1 and T2).

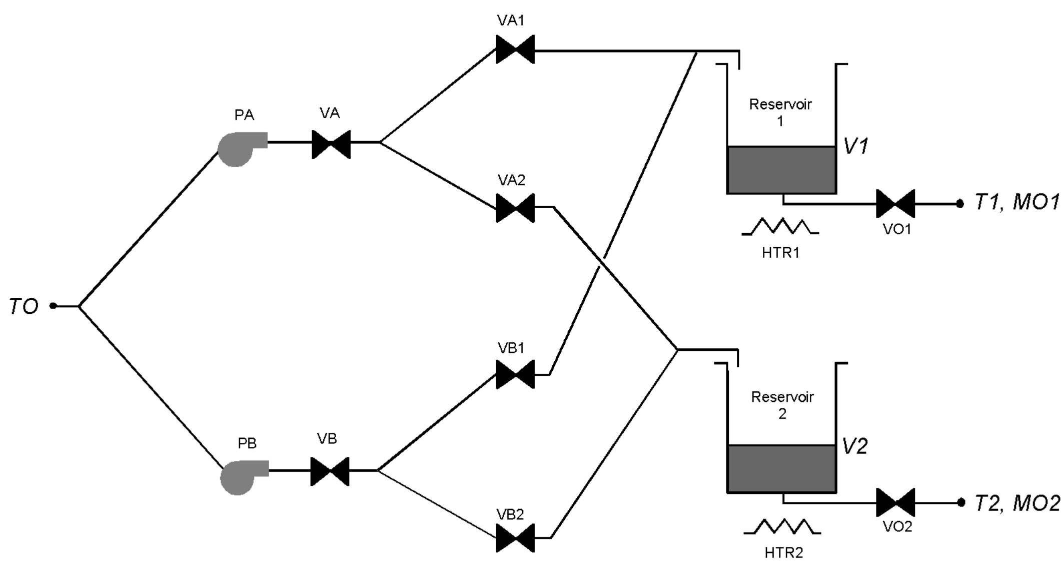


Figure A1: A schematic diagram of the DURESS II process control microworld (Vicente, 1999).

Two different interfaces for the same microworld were developed for the purpose of conducting laboratory experiments (Vicente & Rasmussen, 1990; Pawlak & Vicente, 1996). The P interface (Figure A2a) displays primarily physical information about the work domain. In contrast, the P+F interface (Figure A2b) displays both physical and functional information about the work domain.

(a) (b)

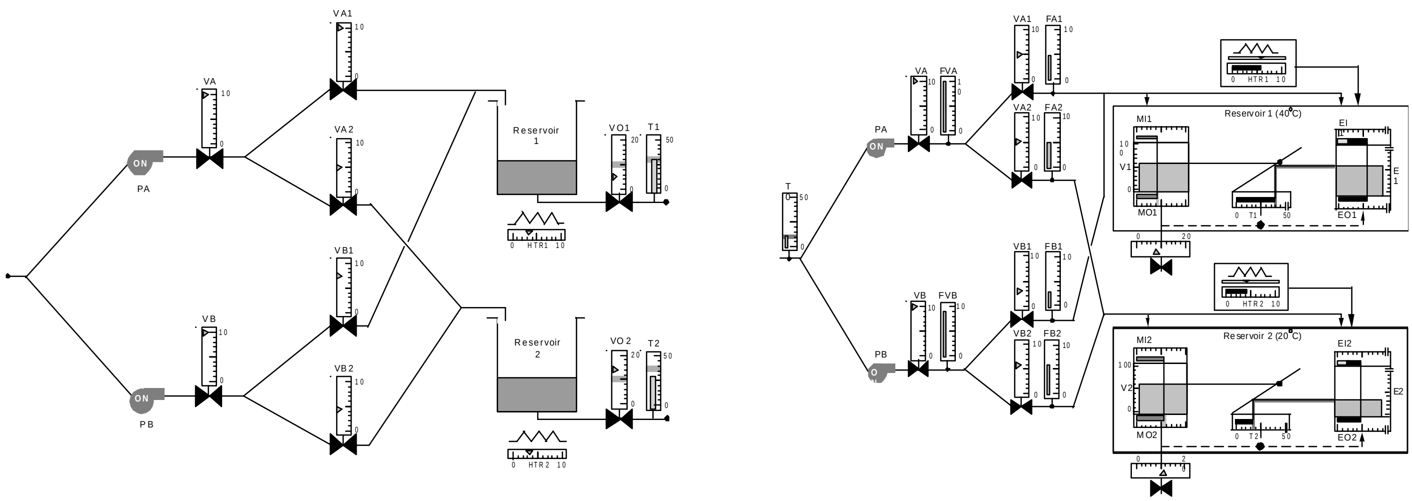


Figure A2: Human-computer interfaces for DURESS II – (a) P interface, (b) P+F interface (Vicente, 1999).

Appendix B: Trial Manipulation Matrix

Experiment 1: Configuration Parameters																				
							Time Constant													
Trial	Strategy	D1	D2	T1	T2	Factor	P1	P2	P1-time	P2-tim	VA	VA1	VA2	VB	VB1	VB2	HTR1	HTR2	VO1	VO2
1	s	5	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
2	d	10	7	40	20	5	25	25	25	25	25	25	25	25	25	25	75	75	25	25
3	f	5	12	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
4	s	3	1	40	20	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5	0.5	0.5
5	s	1	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
6	f	13	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
7	d	9	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
8	f	13	1	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
9	d	3	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
10	s	1	8	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
11	f	5	11	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
12	d	8	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
13	f	12	7	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
14	s	4	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
15	d	2	10	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
16	f	5	15	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
17	d	10	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
18	d	8	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
19	s	4	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
20	f	11	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
21	s	5	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
22	d	10	7	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
23	f	5	12	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
24	s	3	1	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
25	s	1	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
26	f	13	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
27	d	9	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
28	f	13	1	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
29	d	3	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
30	s	1	8	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
31	f	5	11	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
32	d	8	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
33	f	12	7	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
34	s	4	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
35	d	2	10	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
36	f	5	15	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
37	d	10	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
38	d	8	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
39	s	4	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
40	f	11	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
41	s	5	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
42	d	10	7	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
43	f	5	12	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
44	s	3	1	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
45	s	1	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
46	f	13	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
47	d	9	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
48	f	13	1	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
49	d	3	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
50	s	1	8	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
51	f	5	11	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
52	d	8	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
53	f	12	7	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
54	s	4	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
55	d	2	10	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
56	f	5	15	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
57	d	10	5	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
58	d	8	9	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
59	s	4	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
60	f	11	2	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
61	s	5	3	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
62	d	10	7	40	20	5	25	25	25	25	25	25	25	25	25	25	75	75	25	25
63	f	5	12	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
64	s	3	1	40	20	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5	0.5	0.5
65	s	1	9	40	20	7.5	38	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	113	113	37.5	37.5
66	f	13	6	40	20	5	25	25	25	25	25	25	25	25	25	25	75	75	25	25
67	d	9	3	40	20	10	50	50	50	50	50	50	50	50	50	50	150	150	50	50
68	f	13	1	40	20	2.5	13	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	37.5	37.5	12.5	12.5
69	d	3	9	40	20	0.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	7.5	7.5	2.5	2.5
70	s	1	8	40	20	10	50	50	50	50	50	50	50	50	50	50	150	150	50	50
71	f	5	11	40	20	5	25	25	25	25	25	25	25	25	25	25	75	75	25	25
72	d	8	5	40	20	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5	0.5	0.5
73	f	12	7	40	20	7.5	38	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	113	113	37.5	37.5
74	s	4	6	40	20	1	5	5	5	5	5	5	5	5	5	5	15	15	5	5
75	d	2	10	40	20	2.5	13	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	37.5	37.5	12.5	12.5
76	f	5	15	40	20	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5	1.5	0.5	0.5
77	d	10	5	40	20	10	50	50	50	50	50	50	50	50	50	50	150	150	50	50
78	d	8	9	40	20	7.5	38	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	113	113	37.5	37.5
79	s	4	2	40	20	0.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	7.5	7.5	2.5	2.5
80	f	11	2	40	20	2.5	13	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	37.5	37.5	12.5	12.5

Appendix C1: Experiment Materials

Introduction Session – Day 1

This experiment addresses the problem of coordination and adaptation for complex work environments, such as power plants. Specifically, it will investigate operators' adaptation to global changes in process dynamics (i.e., time constant variations). As a participant in this experiment, you will be asked to work with one of two different interfaces for a thermal-hydraulic work domain. While working with these interfaces, you will be required to start-up the process work domain and achieve the goals with a steady state condition.

In this session, you will participate in a test that we will use to place you in an experimental group. Because our experimental groups need to be balanced with respect to the results of this test, we will notify you soon as to whether or not we were able to place you in an experimental group. Not being placed in an experimental group does not imply that you performed poorly on this test. Rather, we were just not able to match your results with those of another subject to promote a balanced experimental design. In any case, you will be paid $10 for your participation in this test, and it should take you approximately one hour. Please note that if you are not selected for this experiment, we may contact you to see if you would like to participate in further phases.

Since our investigation will take a significant amount of time, it is important that you understand from the outset the scope of our study. If you are chosen to participate in our study, you will be required to participate in 20-25 sessions that will each be approximately one hour in duration. You will be asked to establish a weekly experimental schedule that will guarantee that you finish all 20-25 sessions in as close to 20-25 business days as possible. You will be paid $6 per session, with a possible bonus of $2 per session for good performance. In addition, if you complete the experiment, you will be paid an extra $2 per session. In total, then, you stand to be compensated up to $10 per session.

During some parts of the experiment, you will be asked to comment on your thought processes in controlling the work domain. You are also encouraged to offer any opinions, questions, comments, suggestions, or any other information about the experiment or the experimental work domain. Please try to keep this in mind at all times throughout the experiment. Your comments are important!

I would also like to emphasize that you should not discuss this experiment with any other current or potential future participants.

Finally, you are able to withdraw from this experiment at any time, and in that case have the right to ask that all data collected about your performance be given to you or destroyed.

Do you have any questions about what this experiment will involve?

Appendix C2: Experiment Materials

- CONSENT TO TAKE PART IN RESEARCH -

I hereby agree to act as a participant in an experiment entitled:

Adaptation to Global Changes in Process Dynamics

I acknowledge that I have been given a full description of what I shall be required to do in this investigation and I am aware that I may withdraw from the investigation at any time, and that I have the right to ask in that case for any data collected about my performance, including audiotapes, to be given to me or destroyed.

I consent to take part in this investigation voluntarily and without any coercion.

Name: ______________________________

Signature: ______________________________

Address: ______________________________

____

____

Date: ______________________________

Phone: ______________________________

Email: ______________________________

Appendix C2: Experiment Materials

- INITIAL QUESTIONNAIRE -

Participant ID:______________________

Age: ______________________

Gender: ______________________

1. What academic program are you in (i.e., Mechanical Engineering, Industrial Engineering)?

   ____

2. What year are you in (i.e., 1^{st}, 2^{nd}, 3^{rd}, or 4^{th})?

   ____

3. Rate your level of experience using computers on a scale of 1 to 5, where 1 = complete novice and 5 = expert user (circle the appropriate response).

   1 2 3 4 5

4. How many university-level courses in thermodynamics and/or thermal-hydraulics have you taken? For the purposes of this questionnaire, a half-year course (i.e., one term in duration) is considered as one course and a full-year course (i.e., two terms in duration) is considered as two courses.

   ____

5. How many university-level physics courses have you taken? (Do not include courses listed in question 4.)

   ____

6. Are you familiar with or have used the DURESS II simulation program?

   YES NO

Appendix C3: Experiment Materials

Spy Ring History Test (1-1.5 hrs) **Participant:______________________________**

Step	Instructions	Complete
1	Read aloud **Practice Task: Instructions**.	
2	Give the participant the **Practice List** and say "You may use the sheet provided to make any notes that you would like; however, I will take back the sheet when I test you".	
3	Test as required (verbal).	
4	The participant should answer the questions on **Practice Test: Answer Sheet** once the list is learned to criterion. If the participant is going drastically wrong, show them the right direction, but do not give them the answers to the questions. Once all of the questions are completed, go over the answers and ask them if they have any questions before going on to the main task.	
5	Read aloud **Spy Ring History Test: Instructions**. Pause after the first paragraph to emphasise that spies do not change countries during the period, and that the country they live in is the country from which they send messages. Pause at the end of the instructions to emphasise that there are five lists; after each list the subjects will be asked questions on that list, and at the end they will be asked questions concerning all of the lists together. If you don't emphasise this then people are prone to learn the lists trivially and forget them by the end of the test, thus making the test less diagnostic.	
6	Give the participant each list and say, "You may use the space provided to make any notes that you would like, however, I will take back the sheet when I test you."	
7	When testing subjects, read aloud the list number, year, and countries each time.	
8	On the **Overall Questions Answer Sheet** question number 6, give participants all five parts at once. Tell them, "This question asks you to write down the original lists. You are required to reproduce the lists for all five years, but in a scrambled order. Please do them in the order presented, from (a) to (e), and give me each list when you are finished with it." Don't allow them to go back and revise their answers once they have moved on to the list for another year. If the participant insists that they do not remember any or all lists, insist that they give their best guess.	
9	Give similar instructions for question 7.	

***Practice task: Instructions (Read to Participant)**

In this test, we are not interested in how *well* you perform. We *are* interested in how you go about the task.

The basic task is to learn the form of communication networks that are presented to you as lists of communication links between members of the network.

This practice example shows you what is meant. **1 → 2** means that 1 can transmit to 2, and so on.

Please read through the practice list, and when you think you can remember the form of the network I will test you by calling out the left-hand members of each line and asking you to call out the right-hand member. If any errors occur, the list will be returned to you to re-learn, and the test will be repeated. When you recall the items with no errors, I will ask you some questions about the network.

Practice List

1	→	2
2	→	3
6	→	1
3	→	4
6	→	4
7	→	4
4	→	5
7	→	6

Practice Task – Answer Sheet

1. How can a message be transmitted from 1 to 4?

2. How can a message be transmitted from 5 to 7?

3. Please write out the original list in the order it was presented.

4. Please draw out the network as a directed graph, i.e., each number is a node and the links are shown by arrows connecting the nodes.

***Spy ring history task: Instructions (Read to Participant)**

The following lists reveal communication networks of an espionage organisation operating in certain countries. For diplomatic reasons, these countries have been given the imaginary names Ruritania, Dionysia, and Olympia. An agent in the network is given a code name (a letter of the alphabet) and in the period concerned, from 1880 to 1900, all communication took place by one agent passing information to his nearest neighbours (who may or may not be able to convey information in the other direction, depending on their political status at the time). **Agents have one known country of residence (they either and only live in Ruritania, Dionysia, or Olympia) from which they *send* messages.** Time is an important factor because the network changed a good deal between 1880 and 1900.

All of the materials refer to the same nations and the same (alphabetically labelled) individual agents, but successive lists refer to the structures observed in 1880, 1885, 1890, 1895, and 1900.

After learning the five lists, you will be asked questions. Some of them have no correct answer in the ordinary sense. In other words, any answer that fits the data may be correct, and there may be several such answers for each question. Occasionally there will be questions that can only be answered by expressing your opinion. In fact, these are questions where you are asked to add to the body of historical knowledge about espionage in the last century by making reasonable, but in the absence of further data, "possibly false" guesses.

Some of the questions will ask you to recall *all* of the five lists, so please try to learn the information thoroughly. There is no time limit.

List 1 (1880)

Country of Origin	*Transmitter*		*Receiver*
Ruritania	A	→	E
	B	→	A
Dionysia	C	→	D
	C	→	E
	D	→	C
Olympia	E	→	A
	E	→	B
	E	→	D

List 1 (1880) – Answer Sheet

1. How can a message be transmitted from A to D?

2. Is there any other way? If so, what is it?

3. How can a message be transmitted from C to A?

4. Is there any other way? If so, what is it?

List 2 (1885)

Country of Origin	*Transmitter*		*Receiver*
Ruritania	A	→	E
	A	→	B
	B	→	A
	B	→	E
Dionysia	C	→	D
	C	→	E
	D	→	E
Olympia	E	→	C

List 2 (1885) – Answer Sheet

1. How can a message be transmitted from A to D?

2. Is there any other way? If so, what is it?

3. How can a message be transmitted from D to B?

4. Is there any other way? If so, what is it?

List 3 (1890)

Country of Origin	*Transmitter*		*Receiver*
Ruritania	A	→	B
	B	→	A
Dionysia	C	→	D
	D	→	C
	C	→	E
	D	→	E
Olympia	E	→	C
	E	→	D

List 3 (1890) – Answer Sheet

1. How can a message be transmitted from E to D?

2. Is there any other way? If so, what is it?

3. How can a message be transmitted from A to C?

4. Is there any other way? If so, what is it?

List 4 (1895)

Country of Origin	*Transmitter*		*Receiver*
Ruritania	A	→	B
	B	→	E
Dionysia	C	→	D
	D	→	C
	D	→	E
Olympia	E	→	A
	E	→	B
	E	→	C

List 4 (1895) – Answer Sheet

1. How can a message be transmitted from A to C?

2. Is there any other way? If so, what is it?

3. How can a message be transmitted from D to B?

4. Is there any other way? If so, what is it?

List 5 (1900)

Country of Origin	*Transmitter*		*Receiver*
Ruritania	A	→	B
	A	→	E
	B	→	A
Dionysia	C	→	D
	C	→	E
	D	→	C
	D	→	E
Olympia	E	→	B

List 5 (1900) – Answer Sheet

1. How can a message be transmitted from A to C?

2. Is there any other way? If so, what is it?

3. How can a message be transmitted from D to B?

4. Is there any other way? If so, what is it?

Overall Questions – Answer Sheet

1. In what year was the network fragmented into two isolated parts?

2. What is there in common between the organizations existing in 1885 and 1890?

3. Which agent or agents in 1880 were most important for the integrity of the organization?

4. State the names of the three countries and the code names of agents resident in each country.

5. Draw a map showing the arrangement of the countries with respect to shared borders.

6a. Write out the list for 1890.

6b. Write out the list for 1895.

6c. Write out the list for 1880.

6d. Write out the list for 1900.

6e. Write out the list for 1885.

7a. Draw the organisation as it was in 1885 as a directed graph.

7b. Draw the organisation as it was in 1890 as a directed graph.

7c. Draw the organisation as it was in 1880 as a directed graph.

7d. Draw the organisation as it was in 1900 as a directed graph.

7e. Draw the organisation as it was in 1895 as a directed graph.

8a. What do you suppose happened politically between 1880 and 1900?

8b. Did you just consider the issues of 8a for the first time?

8c. What do you suppose will happen in the future?

Overall Questions – Scoring Key

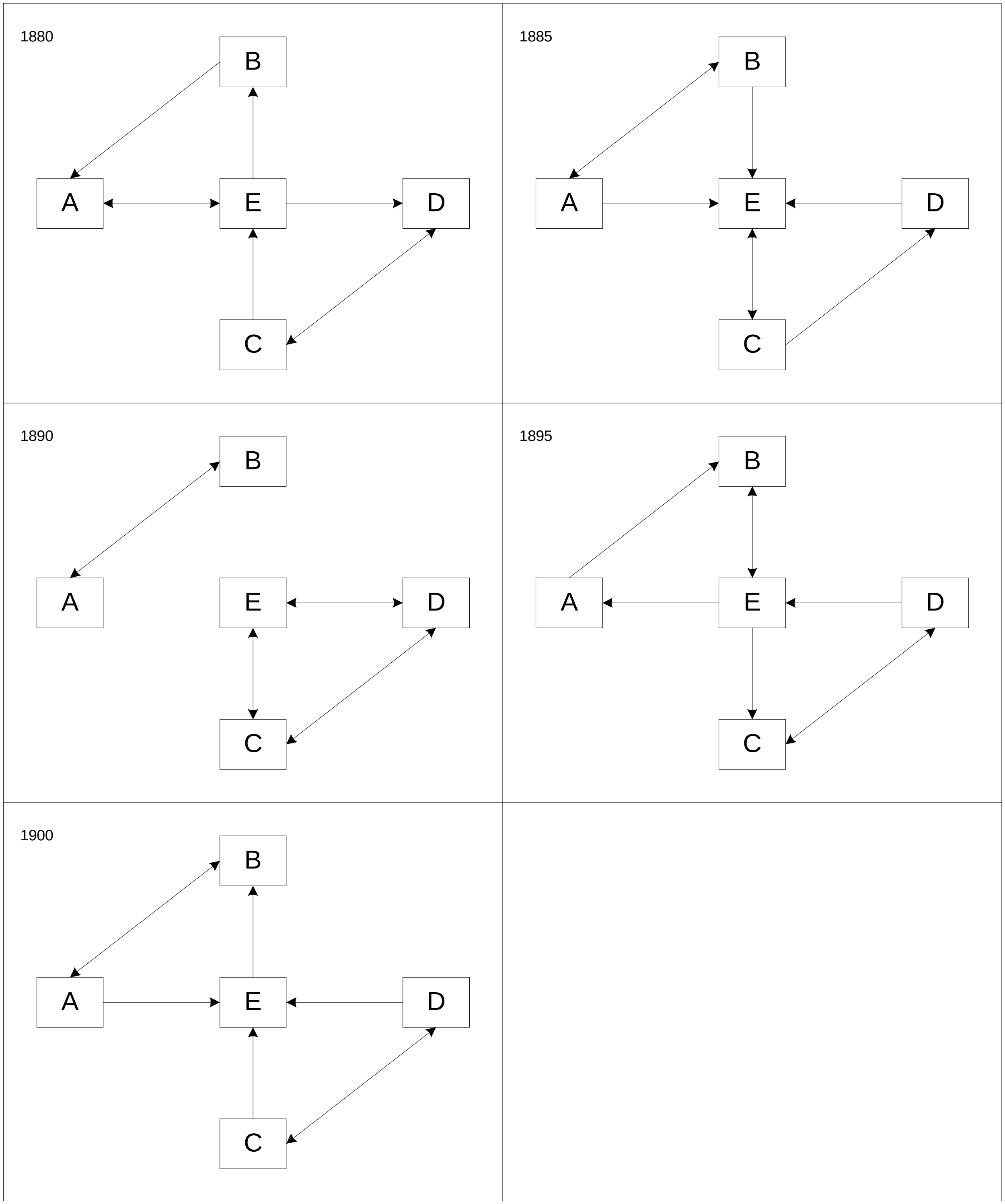
1.	1890	Score 10
	other	Score 0
2.	A→B, B→A, E→C, C→E, C→D, D→E	Score 10
	Some of these items or general correct statement	Score 5
	Other	Score 0
3.	E	Score 10
	other	Score 0
4.	Totally correct (minor sp. Errors OK)	Score 10
	Majority correct	Score 5
	other	Score 0
5.	Ruritania/Olympia/Dionysia	Score 10
	other	Score 0
6.	Each correct pair	Score 1
	Correct placement (order) of pair	Score 1
	Excess pairs (beyond 8)	Score -1
7.	Each correct link	Score 1
	Excess pairs (beyond 8)	Score -1
8a	Answers referring to the breakdown of relations between Dionysia and Ruritania	Score 10
	Other plausible answers	Score 5
	Other answers	Score 0
8b	No	Score 10
	Yes	Score 0
8c	Any plausible/non-trivial answer	Score 10
	Others	0

Holist score: Total of (1,2,3,5,8)/70

Serialist score: Total of (4,6) / 90

Neutral score: Total of 7 / 40

SRT Networks



Appendix C4: Experiment Materials

Tutorial Session – Day 2

This experiment addresses the problem of coordination and adaptation for complex work environments, such as power plants. Specifically, it will investigate operators' adaptation to global changes in process dynamics (i.e., time constant variations). As a participant in this experiment, you will be asked to work with one of two different interfaces for a thermal-hydraulic work domain. While working with these interfaces, you will be required to start-up the process work domain and achieve the goals with a steady state condition.

I will now discuss a number of important points about the experiment. These points are important, and as you are committing yourself to participate for a considerable amount of time, please pay attention to this introduction, and feel free to ask for any clarification.

Since our investigation will take a significant amount of time, it is important that you understand from the outset the scope of our investigation. You will be participating in 20-25 sessions that will each be approximately one hour in duration. You will be asked to establish a weekly experimental schedule that will guarantee that you finish all 20-25 sessions in as close to 20-25 business days as possible. You will be paid $6 per session, with a possible bonus of $2 per session for good performance. In addition, if you complete the experiment, you will be paid an extra $2 per session. In total, then, you stand to be compensated up to $10 per session.

During some parts of the experiment, you will be asked to comment on your thought processes in controlling the work domain. You are also encouraged to offer any opinions, questions, comments, suggestions, or any other information about the experiment or the experimental work domain. Please try to keep this in mind at all times throughout the experiment. Your comments are important!

I would also like to emphasize that you should not discuss this experiment with any other current or potential future participants.

Finally, you are able to withdraw from this experiment at any time, and in that case have the right to ask that all data collected about your performance be given to you or destroyed.

Do you have any questions about what this experiment will involve?

The purpose of today's session is twofold. First, you will be introduced to the work domain that you will be working with for the duration of this experiment. This introduction will include a technical description of this work domain and a number of small tests to confirm your understanding of the work domain. Second, you will be introduced to the interface that will be used during the experiment. There will be an exercise to capture how you would control the work domain . Finally, we will together try to determine the best possible daily schedule for you to come in for sessions over the next approximately 5-6 weeks.

Appendix C5: Experiment Materials

Technical Description of Duress II

Introduction

DURESS (DUal REservoir Work domain Simulation) is a thermal-hydraulic process simulation that you will be working with in this experiment. This description is meant to familiarize you with the characteristics of this work domain. The physical structure of DURESS is illustrated in the accompanying diagram; as you read the work domain and component descriptions, please refer to this diagram. You will be required to redraw and correctly label this diagram from memory at the end of this session.

Objectives

This session is intended to teach you the physical structure of DURESS and the functions of each of its components.

DURESS

The DURESS work domain consists of two redundant feedwater streams (fws's), **fws A** and **fws B**. These streams can be configured to supply water to two reservoirs, **Reservoir 1** and **Reservoir 2**. The goals of the work domain are to keep each of the reservoirs at a prescribed temperature (40°C for Reservoir 1 and 20°C for Reservoir 2), and to maintain enough water in each reservoir to satisfy each of the current demand flow rates (**D1** and **D2**), which are externally determined. To satisfy these work domain goals, there are eight valves, two pumps, and two heaters. DURESS has been modelled to be consistent with the laws of physics (e.g. conservation of mass and energy). However, several simplifying assumptions have been made.

Before describing each of the components of DURESS, a description of the component coding work domain will be given. Codes for all components — except for heaters — begin with the first letter of the component name:

Valves ⇒ **V**
Pumps ⇒ **P**
Reservoirs ⇒ **R**

Heater codes begin with a three letter mnemonic:

Heaters ⇒ **HTR**

As mentioned in above, DURESS also has two feedwater streams:

Feed**w**ater **S**tream **A** ⇒ **fws A**
Feed**w**ater **S**tream **B** ⇒ **fws B**

These letters (A and B) are used in the component code to describe the components in each of the respective fws's. For example, valves in fws A are labelled with the suffix **A** to get the descriptor **VA**. The final digit in some of the component codes refers to the reservoir that a component is directly connected to. For example, the valves connected to reservoir 1 are designated **VA1**, **VB1**, and **VO1** (where 'O' stands for 'output'). This naming convention is used for all of the components of DURESS.

The DURESS components will now be described in detail. Be sure to refer to the DURESS diagram as you read the descriptions so that you can learn the location and names of the components.

Source of Water

Both **fws A** and **fws B** are connected to an unlimited external source that supplies a net positive suction head. Thus, there is always water available. Ordinarily, the temperature of the incoming water is 10°C.

Feedwater Streams

Each input feedwater stream (**fws A** and **fws B**) consists of one pump (**PA** or **PB**) and three valves (**VA**, **VA1**, and **VA2**; **VB**, **VB1**, and **VB2**). The two streams are functionally identical, each having a capacity for attaining a maximum flowrate of 10 units/second. Thus, the combined feedwater supply capacity of the two streams is 20 units/second. Using these valves, each feedwater stream can be configured to supply water to either, both, or neither of the two reservoirs.

The feedwater streams terminate at the reservoirs which they feed, and water leaves the work domain through the output valves connected to the reservoirs, **VO1** and **VO2**. The combined output capacity of these two valves is 20 units/second.

Piping

The pipes are assumed to be perfectly insulated. Thus, there will be no transfer of heat between the water in the pipes and the surrounding environment. It is assumed that the pipes are sufficiently large in diameter that their pressure losses are much smaller than those caused by the valves; therefore the resistance of the pipes is ignored. Note also that the length of the pipes from each of the end valves (**VA1**, **VA2**, **VB1**, **VB2**) to each reservoir is the same.

Valves

Six of the eight valves are identical (**VA**, **VA1**, **VA2**, **VB**, **VB1**, and **VB2**). These valves have settings with a linear range from 0 (completely closed) to 10 (all the way open). The maximum flowrate through any of these valves is 10 units/second. The output valves (**VO1** and **VO2**) are slightly different in that they can be set from 0 (completely shut) to 20 (all the way open). Thus the maximum flow through these valves is 20 units/second. It is assumed that these valve settings directly specify the <u>flowrates</u> (or the flowrate ratios, when appropriate) rather than <u>flow resistances</u>.

Pumps

The two pumps (**PA** and **PB**) are functionally identical. They have a discrete setting, either ON or OFF. Each pump has the capacity to achieve a maximum flowrate of 10 units/second.

Heaters

The two heaters (**HTR1** and **HTR2**) are also functionally identical. They have a continuous control setting ranging from 0 (off) to 10 (maximum heat flow). Since the input water to each of reservoirs is 10°C, both reservoirs require a heater to attain their respective temperature setpoints (20°C and 40°C).

Reservoirs

The two reservoirs (**R1** and **R2**) are of identical size, and their maximum volume is 100 units. It is assumed that the reservoirs are perfectly insulated. Thus, there is no heat transfer between the water in the reservoirs and the surrounding environment.

Demand

The demand goals (**D1** and **D2**) are the desired outputs for each reservoir. The dynamics associated with a pressurehead in the reservoir (i.e., the force of gravity on the water) are not considered. Furthermore, the demands for the two reservoirs need not be the same and can change from trial to trial. The demand for each reservoir can range from 0 units/second (no demand) to 20 units/second (full demand), with the added constraint that the combined demands from the two reservoirs does not exceed 20 units/second, since this is the capacity of the two feedwater streams.

Summary

In this section you have learned that the goals of the work domain are to keep each of the reservoirs at a prescribed temperature (40°C for Reservoir 1 and 20°C for Reservoir 2), and to maintain enough water in each reservoir to satisfy each of the current demand flowrates (D1 and D2), which are externally determined. You have also learned that DURESS is made up of two feedwater streams, consisting of one pump and three valves. These feedwater streams lead into two reservoirs which can be heated using the heaters. Each reservoir has one valve to control the output flowrate. These components are coded based on the name of the component, the feedwater stream the component belongs to, and the reservoir that the component is connected to, where appropriate.

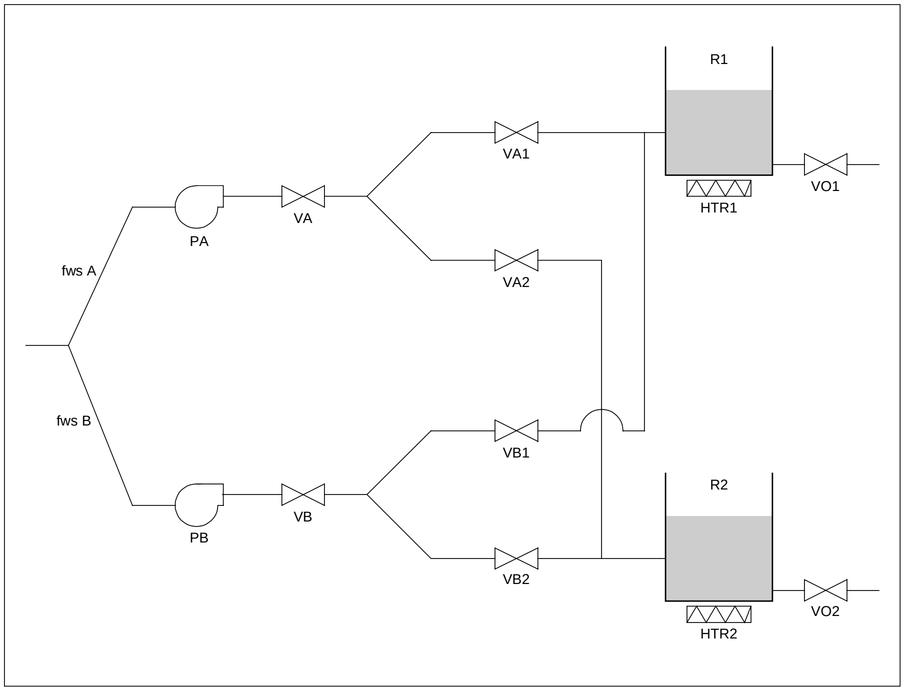


Figure C1: Schematic of Duress

These activities are to be administered by the experimenter.

Activity 1:

1. What two goals must be satisfied to successfully operate DURESS?
2. Using the unlabeled diagram of DURESS, point to:
   - Reservoir 1
   - fws B
   - VO1
   - The heater for reservoir 2
   - Pump B
   - VB1
   - The valve in feedwater stream A directly connected to reservoir 2

The experimenter should give feedback during these activities.

Activity 2:

Label the following diagram of DURESS.

Test

Sketch the physical diagram of DURESS and label the components using the naming conventions described earlier.

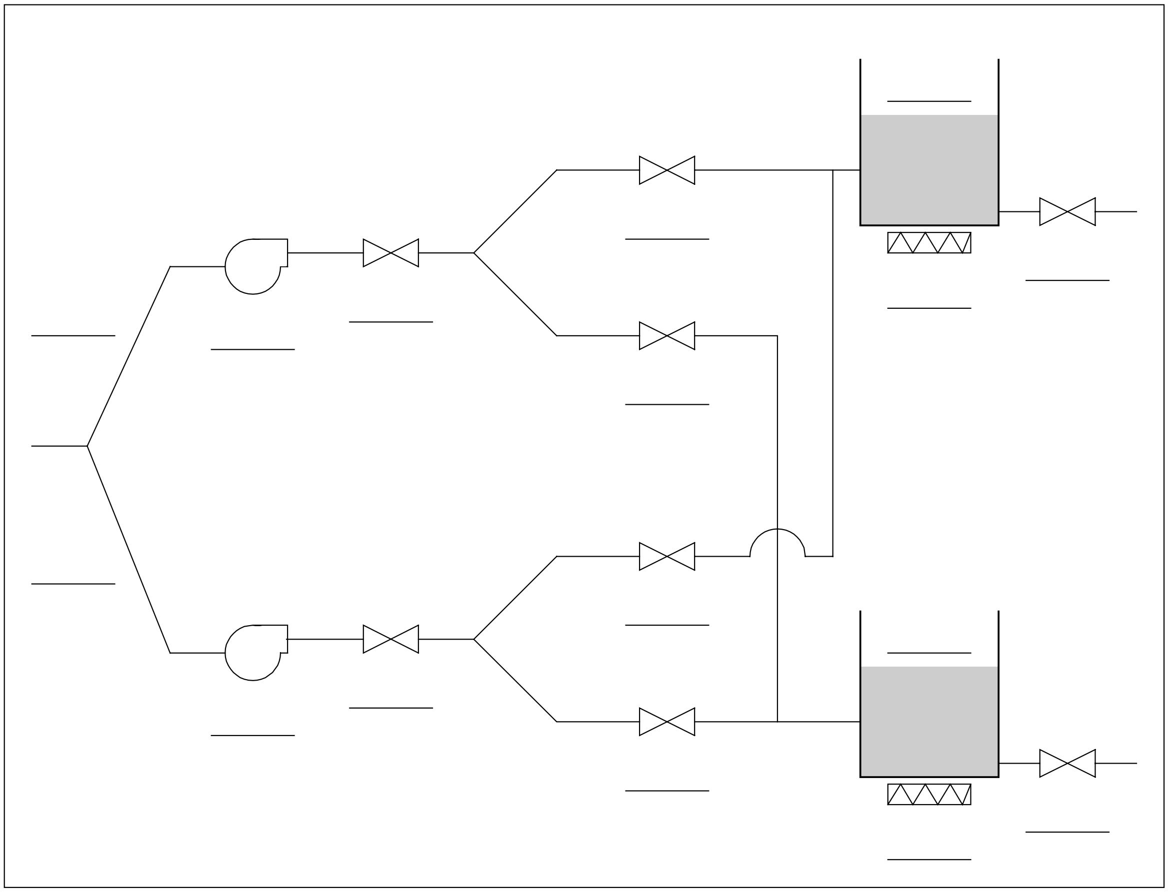


Figure C2: Diagram used for testing participants on work domain components.

PROCEDURE: P INTERFACE

Experimenter Instructions
In the DURESS account on BB, change to the misc directory (cd ~/misc) and use the command "ipaste P.rgb". This will call up a picture of the P interface.
This session should be read aloud by the experimenter to the subject.

Introduction
This description is meant to get you familiar with the characteristics of the interface that you will be using for the experiment. A static view of the interface is presented on the screen in front of you. As the description of the work domain graphics is presented, please refer to this display. You will be required to answer several questions about the interface and the operation of the work domain at the end of this session.

Objectives
This session is intended to teach you the relevant features of the interface that you will be using for this experiment so that you can operate DURESS.

The P Interface
This is the interface that you will be using for the experiment. [*For the following text, point where appropriate*.] The input water temperature is shown in thermometer T0. The pump settings (for example, PB) are discrete (that is, either ON or OFF), and are therefore directly labelled on the pumps themselves. [*Indicate to the subject how to turn the pump off and on.*] The valve settings (e.g., VB) range from 0 to 10 and are indicated by the small yellow triangular pointers on the respective scales. [*Indicate to the subject how to set the valves.*] The demands (D1 and D2) can range from 0 to 20 and are indicated by the green areas within the outlet valve indicator (for example, VO1). Volume (V1, V2) can range from 0 to 100 and is indicated by the blue area and the vertical scale on the side of each reservoir. The output temperature (T1, T2) can range from 0 to 50. The heater settings (for example, HTR2) also range from 0 to 10 and are indicated by small, red triangular pointers. [*Indicate to the subject how to set the heater.*] For the temperature settings, the upper and lower limits around the setpoints (40°C and 20°C) are shown as a green area on the two temperature scales (T1 and T2, respectively). These setpoints are fixed.
It is important that you understand how this interface works before we continue. Do you have any questions at this point?

Procedure
During this experiment, you will be directly controlling DURESS. Each trial consists of a 'scenario' of DURESS' behaviour. During some scenarios, the work domain will exhibit a normal pattern of behaviour following the description of DURESS that you read earlier. During other scenarios, changes in the dynamics of the work domain may occur during operation. Please keep in mind, however, that for this experiment there will be no simulated sensor failures (e.g., if the reservoir graphic shows that the reservoir is half-full, then that reservoir is indeed half-full).
There are two different types of trials that you may encounter while controlling DURESS. These are as follows:

1. Start-up (Reference value 1): For this task, you will be presented with a shut-down work domain and will be asked to bring the work domain on-line to satisfy two goals: temperature goals (R1 to 40°C, R2 to 20°C) and output demand goals (D1 and D2). For each trial it is your task to ensure that temperature and output flow demands are being met. These goals must be met until the work domain is brought to "steady-state", where "steady-state" implies that all work domain goals (temperature and output) for both reservoirs have been met for five consecutive minutes. At the end of this time (i.e., when "steady-state" is reached), the trial will end automatically.
2. Start-up (Reference value changes): The task is the same as #1, but the process dynamics change so that the component actions move slower or faster.

Summary

In this section, you have learned what the interface graphics mean. The valve and heater graphics indicate their settings and the pump graphics indicate whether the pump is off or on. For each reservoir there is a graphic which describes the volume of water in that reservoir.
You have also learned that you are required to ensure that the temperature and output demands for both reservoirs are met for a period of five consecutive minutes.
Do you have any questions?

Test

[*The experimenter should correct subjects if they get an answer incorrect. If subjects answer one or more questions incorrectly, then repeat this entire module until they are able to answer the following questions correctly.*]
Use the mouse to indicate the answers to the following questions and verbalise responses where necessary. [*Subjects are required to point with the mouse to the relevant area of the screen for each of the following questions, even if the answer can be easily verbalised.*]

1. Where is the input thermometer?
2. What is the input temperature? [*10 degrees*]
3. Show how you would turn a pump on.
4. Show how you would increase the setting of VA1.
5. What is the setting of VB2? [*8*]
6. What is the setting of HTR1? [*4*]
7. What is the volume of reservoir 2? [*about 45*]
8. What is the output flow demand for reservoir 1? [*8*]
9. What is the temperature goal for reservoir 2? [*20 degrees*]
10. Does this temperature goal ever change? [*no*]

The following questions do not require an interface picture.

1. When is "steady-state" achieved? [*When the work domain demands have been met for both reservoirs for five consecutive minutes.*]

PROCEDURE: P+F INTERFACE

Experimenter Instructions

In the DURESS account on BB, change to the misc directory (cd ~/misc) and use the command "ipaste P+F.rgb". This will call up a picture of the P interface.
This session should be read aloud by the experimenter to the subject.

Introduction

This description is meant to get you familiar with the characteristics of the interface that you will be using for the experiment. A static view of the interface is presented on the screen in front of you. As the description of the work domain graphics is presented, please refer to this display. You will be required to answer several questions about the interface and the operation of the work domain at the end of this session.

Objectives

This session is intended to teach you the relevant features of the interface that you will be using for this experiment so that you can operate DURESS.

The P+F Interface

This is the interface that you will be using for the experiment. [*For the following text, point where appropriate.*] The feedwater streams on the left-hand side of the screen will be described first. The input water temperature is shown on the thermometer T0. The pump settings (for example, PB) are discrete (that is, either ON or OFF), and therefore are directly labelled on the pumps themselves. [*Indicate to the subject how to turn the pumps on and off.*] The valve settings (for example, VB) range from 0 to 10 and are indicated by the small, yellow triangular pointers on the respective scales. [*Indicate to the subject how to set the valves.*] The flowrates for each valve range from 0 to 10 and are indicated by yellow bars next to the respective valves. [*Point to the flowmeters for VA, VA1, etc.*] The output valve setting (for example, V01) is below the mass balance graphic and is indicated by a yellow triangle. The yellow bar on the bottom of the mass balance graphic shows the flowrate for this output valve. (The mass balance graphic will be explained below.) Note that the scale for the output valve setting ranges from 0 to 20, which is the same scale that is used for mass input and output flowrates to and from the reservoir. [*Point to this on the screen.*] The heater settings (for example, HTR2) range from 0 to 10, with a red triangle as an indicator. [*Indicate to the subject how to set the heater.*] The heat transfer rates are displayed next to the heater settings as red bars. Note that the heat transfer rate and the heater settings are the same.
The status of the reservoirs is represented by the graphics on the right half of the screen. The blue graphic on the left represents the mass balance for the reservoir, while the orange graphic on the right represents the energy balance. Both operate in a similar manner. Referring to reservoir 1, the various inputs are shown at the top (for example, MI1 for the mass and EI1 for the energy), the outputs at the bottom (e.g., M01 for demand, or mass, and E01 for energy) and the inventories on the side (e.g., V1 for volume or mass, and E1 for energy). The energy inputs (EI1 and EI2) are partialled out according to the two contributors indicated by the flow lines. Thus, the yellow bar shows the energy added by the feedwater, while the red bar shows the energy added by the heater. The energy output (e.g., E01) is proportional to the product of temperature (T1) and demand (M01) as indicated by the dotted flow lines connecting these three variables.

Intuitively, the energy and mass graphics rely on a funnel metaphor. Thus, if the bottom is wider than the top (that is, output is greater than input), then it is easy to visualize the consequence, namely that volume should be decreasing. Thus, the slope of the line represents the rate at which the mass (or energy) should be changing. If input equals output, then the line would be vertical, indicating that the inventory should not change.

The graphic in the middle, between the mass and energy balances, illustrates the structure of the relationship between volume, energy, and temperature. A change in the height of the horizontal bar that emanates from the current volume level line should always accompany any change in volume (that is, the bar will always be at the same height as the water level in Reservoir 1 or 2). The diagonal line in the centre display is always tangent to the ball on the edge of the horizontal line. Thus, a change in the vertical position of the horizontal bar serves to change the slope of the line in the centre display. For example, if the volume increases, the horizontal line goes up, causing the diagonal to rotate counter-clockwise, and thereby increasing the slope of the diagonal line. The slope of the diagonal represents the function that maps the amount of energy onto temperature. This mapping is indicated by the red line from the energy inventory (E1, E2) that comes across and reflects off the diagonal and down onto temperature (T1, T2). For the temperature settings, the upper and lower limits around the setpoints (40°C and 20°C) are shown as a green area on the two temperature scales (T1 and T2, respectively). This green goal area is projected up and reflects off the diagonal line to the energy reservoir indicating the goal area for the mapping between energy and temperature. The upper and lower limits around the output goals are shown as green areas on the output flowrate meter.

It is important that you understand how this interface works before we continue. Do you have any questions at this point?

Procedure

During this experiment, you will be directly controlling DURESS. Each trial consists of a 'scenario' of DURESS' behaviour. During some scenarios, the work domain will exhibit a normal pattern of behaviour following the description of DURESS that you read earlier. During other scenarios, changes in the dynamics of the work domain may occur during operation. Please keep in mind, however, that for this experiment there will be no simulated sensor failures (e.g., if the reservoir graphic shows that the reservoir is half-full, then that reservoir is indeed half-full).

There are two different types of trials that you may encounter while controlling DURESS. These are as follows:

3. <u>Start-up (Reference value 1)</u>: For this task, you will be presented with a shut-down work domain and will be asked to bring the work domain on-line to satisfy two goals: temperature goals (R1 to 40°C, R2 to 20°C) and output demand goals (D1 and D2). For each trial it is your task to ensure that temperature and output flow demands are being met. These goals must be met until the work domain is brought to "steady-state", where "steady-state" implies that all work domain goals (temperature and output) for both reservoirs have been met for five consecutive minutes. At the end of this time (i.e., when "steady-state" is reached), the trial will end automatically.
4. <u>Start-up (Reference value changes)</u>: The task is the same as #1, but the process dynamics change so that the component actions move slower or faster.

Summary

In this section, you have learned what the interface graphics mean. The valve and heater graphics indicate their settings and the pump graphics indicate whether the pump is off or on. For each reservoir there is a graphic which describes the volume of water in that reservoir.

You have also learned that you are required to ensure that the temperature and output demands for both reservoirs are met for a period of five consecutive minutes.

Do you have any questions?

Test

[*The experimenter should correct subjects if they get an answer incorrect. If subjects answer one or more questions incorrectly, then repeat this entire module until they are able to answer the following questions correctly.*]

Use the mouse to indicate the answers to the following questions and verbalise responses where necessary. [*Subjects are required to point with the mouse to the relevant area of the screen for each of the following questions, even if the answer can be easily verbalised.*]

1. Where is the input thermometer?
2. What is the input temperature? [*10 degrees*]
3. Show how you would turn a pump on.
4. Is the energy entering reservoir 1 more or less than the output? [*more*]
5. Show how you would increase the setting of VA1.
6. What is the flowrate through VB2? [*about 4 or 4.5*]
7. What is the heat transfer rate of HTR1? [*10*]
8. Approximately what percentage of total input energy to reservoir 2 does the input water add? [*about 33%*]
9. What is the mass flowrate into reservoir 1? [*about 10*]
10. Should the volume in reservoir 1 be increasing or decreasing? How can you tell? [*Increasing, because the flow gradient has a positive slope; subjects may also answer that it is increasing because input is greater than output.*]
11. What is the volume of reservoir 1? [*about 80*]
12. What is the output flow demand for reservoir 2? [*4*]
13. What is the actual output flow for reservoir 2? [*19*]
14. What is the temperature goal for reservoir 2? [*20℃*]
15. Does this temperature goal ever change? [*no*]

For the following questions, look at the graphic between the mass and energy reservoirs. [*The experimenter should point to where to look*: *Between mass reservoir 1 and energy reservoir 1.*]

1. If the level in the graphic representing volume increased, what would happen to the temperature reading? [*It would decrease.*]
2. If the graphic representing reservoir volume were kept constant but the level of the graphic representing reservoir energy increased, then what would happen to temperature? [*It would increase.*]

The following questions do not require you to look at the interface picture.

1. When is “steady-state” achieved? [*When the work domain demands of temperature and output have been met for both reservoirs for five consecutive minutes.*]

Appendix C6: Experiment Materials

Control Recipes

Participant: ______________________________

Trial: Pre-trials 60 80

Instructions

In this procedure, your task is to write out a set of instructions for performing a start-up of the DURESS work domain (i.e., for bringing it from a "shut-down" to a "steady-state" condition). Formulate your instructions under the assumption that it will be used by someone who has never seen or used DURESS before. Be specific/detailed in your description; you may use point form.