APPENDIX A:

Trial schedule

The following list represents the complete set of trials presented to subjects in the course of the experiment. The list includes, for each trial, the configuration file which was used to drive the simulation program, the output demand flowrates used for the start-up and tuning (where applicable) portions of the trial, as well as descriptions of any events of special interest.

Trials where the second set of demand flowrates are replaced with two 'X' symbols indicate fault trials where only a start-up task was performed.

Descriptions of faults are given in the form: "(failing component)/(magnitude of failure)/(time of failure)". Reservoir leaks are abbreviated as RL, heater failures as HF, external heat sources as EH. For example a reservoir leak of four units per second in reservoir 2 occuring 6 minutes into the trial would be described by: RL2, -4 @ 6min. All valve blockages are total blockages. Changes in input temperature are described by: "input/(amount of change in input temperature)/time of occurrence". Transfer is abbreviated as "Xfer". Post-hoc explanation is denoted by "PH". Non routine faults are denoted by the letters "NR".

Trial #	config. file	output demand flowrates upper	lower	upper	lower	Description	Event
						Introductory Session	Test Day #1
1	Jt1.cf	8	2			Start-up Trials begin	
2	Jt2.cf	2	7				
3	Jt3.cf	3	9				
4	Jt4.cf	7	4				
5	Jt5.cf	9	8				
6	Jt6.cf	8	7				
7	Jt7.cf	4	3				
8	Jt8.cf	2	5				
9	Jt9.cf	5	10				
10	Jt10.cf	3	6				
11	Jt11.cf	7	11				
12	Jt12.cf	5	12				
13	Jt13.cf	6	11				
14	Jt14.cf	8	8				
15	Jt15.cf	8	3				
16	Jt16.cf	5	12				
17	Jt17.cf	2	2				
18	Jt18.cf	2	4				
19	Jt19.cf	3	11				
20	Jt20.cf	8	9				
21	Jt21.cf	5	2				
22	Jt22.cf	3	6				
							Test Day #2
23	Jt23.cf	5	10			Shut-down task added	
24	Jt24.cf	4	5				
25	Jt25.cf	2	7				
26	Jt26.cf	3	5				
27	Jt27.cf	1	18				
28	Jt28.cf	6	12				
29	Jt29.cf	2	5				
30	Jt30.cf	7	2				
31	Jt31.cf	5	13				
32	Jt32.cf	4	8				
33	Jt33.cf	8	5				
34	Jt34.cf	9	3				
35	Jt35.cf	4	11				
36	Jt36.cf	3	8				
37	Jt37.cf	4	6				
38	Jt38.cf	1	10				
39	Jt39.cf	4	12				
40	Jt40.cf	2	9				
41	Jt41.cf	2	7				
42	Jt42.cf	1	6				
43	Jt43.cf	5	5				
44	Jt44.cf	3	4				
45	Jt45.cf	3	11	4	6	Tuning task added	
46	Jt46.cf	5	11	3	6		
47	Jt47.cf	5	2	2	16		
48	Jt48.cf	3	4	6	13		
49	Jt49.cf	4	8	3	16		
50	Jt50.cf	6	6	5	14		
51	Jt51.cf	5	7	8	12		
52	Jt52.cf	8	4	6	13		
53	Jt53.cf	6	2	4	5		
54	Jt54.cf	2	8	3	11		
55	Jt55.cf	1	18	9	1		
56	Jt56.cf	7	11	4	16		
57	Jt57.cf	5	11	6	7		
58	Jt58.cf	3	4	5	6		

Trial #	config. file	output demand flowrates				Description	Event
		upper	lower	upper	lower		
59	Jt59.cf	3	8	2	5		Verbal protocols begin
60	Jt60.cf	5	6	2	1		
61	Jt61.cf	6	7	1	1		
62	Jt62.cf	5	11	6	5		
63	Jt63.cf	8	6	6	13		
64	Jt64.cf	3	16	X	X	VA1 blockage @ 4 min + PH	Fault #1 (protocol recorded)
65	Jt65.cf	4	11	5	14		
66	Jt66.cf	3	15	8	5		
67	Jt67.cf	3	6	6	11		
68	Jt68.cf	6	11	8	4		Verbal protocols end
							Test Day #3
69	Jt69.cf	8	11	7	12		
70	Jt70.cf	6	1	2	2		
71	Jt71.cf	5	2	6	9		
72	Jt72.cf	4	8	2	6		
73	Jt73.cf	7	12	2	5		
74	Jt74.cf	4	15	6	9		
75	Jt75.cf	7	5	5	3		
76	Jt76.cf	4	4	7	11		
77	Jt77.cf	9	3	1	10		
78	Jt78.cf	10	5	7	2		
79	Jt79.cf	6	13	9	5		
80	Jt80.cf	2	9	5	7		
81	Jt81.cf	6	13	5	7		
82	Jt82.cf	3	6	8	11		
83	Jt83.cf	9	9	5	12		
84	Jt84.cf	5	13	4	9		
85	Jt85.cf	4	5	7	11		
86	Jt86.cf	2	12	1	14		
87	Jt87.cf	9	8	3	5		
88	Jt88.cf	6	6	3	13		
89	Jt89.cf	7	11	3	10		
90	Jt90.cf	7	2	5	3		
91	Jt91.cf	4	5	8	4		
92	Jt92.cf	8	1	2	14		Verbal protocols begin
93	Jt93.cf	5	4	8	11		
94	Jt94.cf	4	11	X	X	RL2, -4 @ 2min + PH	Fault #2 (protocol recorded)
95	Jt95.cf	5	12	9	14	2nd demand pr > 20	Quazi-Fault
96	Jt96.cf	7	4	1	8		
97	Jt97.cf	4	12	X	X	HF1, 50% @ 1min +PH (cf. Xfer Fault1)	Fault #3 (protocol recorded)
98	Jt98.cf	2	9	7	11		
99	Jt99.cf	6	13	4	8		
100	Jt100.cf	7	12	5	9		
101	Jt101.cf	4	14	7	2		Verbal protocols end
102	Jt102.cf	8	4	2	2		
103	Jt103.cf	6	8	7	2		
104	Jt104.cf	4	3	6	13		
105	Jt105.cf	6	2	1	15		
106	Jt106.cf	3	6	5	7		
107	Jt107.cf	6	13	5	7		
108	Jt108.cf	2	9	5	7		
109	Jt109.cf	6	1	2	2		
110	Jt110.cf	8	1	6	7		
111	Jt111.cf	4	12	8	1		
112	Jt112.cf	2	7	8	3		
113	Jt113.cf	6	7	X	X	RL2, -7 @ 4 min	Fault #4 (no protocol)
114	Jt114.cf	8	7	3	9		
115	Jt115.cf	5	9	9	1		
116	Jt116.cf	6	8	7	7		
117	Jt117.cf	1	18	7	11		

Trial #	config. file	output demand flowrates				Description	Event
		upper	lower	upper	lower		
. 118	Jt118.cf	6	12	6	9		
119	Jt119.cf	7	4	2	7		
120	Jt120.cf	3	4	1	7		
121	Jt121.cf	8	1	5	6		
122	Jt122.cf	5	3	4	15	(no faults for this protocol period)	Verbal protocols begin
123	Jt123.cf	8	11	1	1		
124	Jt124.cf	4	9	1	11		
125	Jt125.cf	8	9	6	11		
126	Jt126.cf	2	15	8	10		
127	Jt127.cf	6	3	9	6		
128	Jt128.cf	2	12	9	9		
129	Jt129.cf	8	4	5	11		
130	Jt130.cf	2	9	7	11		
131	Jt131.cf	9	3	1	15		
132	Jt132.cf	4	5	6	3		
133	Jt133.cf	1	18	5	14		
134	Jt134.cf	7	11	5	14		
135	Jt135.cf	5	13	4	3		
136	Jt136.cf	3	11	8	1		Verbal protocols end
137	Jt137.cf	3	13	6	2		
138	Jt138.cf	8	4	2	3		
139	Jt139.cf	3	6	9	2		
140	Jt140.cf	6	9	9	4		
141	Jt141.cf	4	7	6	2		
142	Jt142.cf	7	2	6	13		
. 143	Jt143.cf	8	1	8	7		
144	Jt144.cf	5	1	9	3	HF2, 150% @ 8min	Fault #5 (no protocol)
145	Jt145.cf	7	7	3	14		
146	Jt146.cf	6	3	2	5		
147	Jt147.cf	9	9	5	12		
148	Jt148.cf	5	13	4	9		
149	Jt149.cf	4	5	7	11		
150	Jt150.cf	2	12	1	14		
151	Jt151.cf	2	7	8	3		
							Test Day #4
152	Jt152.cf	2	9	8	1		
153	Jt153.cf	8	7	3	9		
154	Jt154.cf	5	9	9	1		
155	Jt155.cf	6	8	7	7		
156	Jt156.cf	5	14	2	3		
157	Jt157.cf	6	2	9	9		
158	Jt158.cf	2	9	6	13		
159	Jt159.cf	7	11	5	3		
160	Jt160.cf	7	9	5	11		
161	Jt161.cf	7	8	5	11		
162	Jt162.cf	4	2	9	3		
163	Jt163.cf	4	3	6	13		Verbal protocols begin
164	Jt164.cf	6	2	1	15		
165	Jt165.cf	8	7	3	9	RL2, -4 @ 9min +PH	Fault #6 (protocol recorded)
166	Jt166.cf	6	13	5	7		
167	Jt167.cf	2	9	5	7		
168	Jt168.cf	6	1	2	2		
169	Jt169.cf	8	1	6	7		
170	Jt170.cf	7	12	3	2	Baseline for narrow tolerance trial (195)	Verbal protocols end
171	Jt171.cf	2	7	8	3		
172	Jt172.cf	2	9	8	1		
173	Jt173.cf	8	7	3	9		
174	Jt174.cf	5	9	9	1		
175	Jt175.cf	6	8	7	7		
176	Jt176.cf	8	8	5	3		

Trial #	config. file	output demand flowrates				Description	Event
		upper	lower	upper	lower		
177	Jt177.cf	4	13	6	2	VB2 blockage @ 7min	Fault #7 (no protocol)
178	Jt178.cf	8	9	6	11		
179	Jt179.cf	2	15	8	10		
180	Jt180.cf	6	3	9	6		
181	Jt181.cf	2	12	9	9		
182	Jt182.cf	2	9	7	11		
183	Jt183.cf	6	3	9	6	HF2, 50% @ 7.5 min + PH	Verbal begins; Fault #8 (rec'd)
184	Jt184.cf	9	3	1	15		
185	Jt185.cf	4	5	6	3		
186	Jt186.cf	8	1	6	7		
187	Jt187.cf	6	7	7	2	VB blockage @ 8min + PH (cf. Xfer Fault2)	Verbal ends; Fault #9 (rec'd)
188	Jt188.cf	2	7	8	3		
189	Jt189.cf	2	9	8	1		
190	Jt190.cf	8	7	3	9		
191	Jt191.cf	5	9	9	1		
192	Jt192.cf	6	8	7	7		
193	Jt193.cf	1	18	7	11		
194	Jt194.cf	6	12	6	9		
195	Jt195.cf	7	12	3	2	Temperature tolerances narrowed	Quazi-Fault
196	Jt196.cf	3	4	1	7		
197	Jt197.cf	8	1	5	6		
198	Jt198.cf	5	3	4	15		
199	Jt199.cf	4	11	5	14		
200	Jt200.cf	3	15	8	5		
201	Jt201.cf	5	11	6	9	RL1, -4 @ 4min; input+6 deg @ 6min +PH	Verbal begins; NR Fault1(rec'd)
202	Jt202.cf	6	11	8	4		
203	Jt203.cf	8	11	7	12		
204	Jt204.cf	6	1	2	2		
205	Jt205.cf	5	2	6	9		
206	Jt206.cf	4	8	2	6		
207	Jt207.cf	7	12	2	5		
208	Jt208.cf	4	15	6	9		
209	Jt209.cf	5	6	3	4	VA blockage @ 7 min; EH(3e3) @ 8 min +PH	Verbal ends; NR Fault2(rec'd)
210	Jt210.cf	4	4	7	11		
211	Jt211.cf	9	3	1	10		
212	Jt212.cf	9	5	7	2		
213	Jt213.cf	6	13	9	5		
214	Jt214.cf	2	9	5	7		
215	Jt215.cf	3	11	2	5		
216	Jt216.cf	8	9	7	2		
217	Jt217.cf	5	2	5	13		Verbal protocols begin
218	Jt218.cf	7	12	5	9	HF1,150%@3min; input+11deg@5min+PH	NR Fault3 (protocol recorded)
							Test Day #5
219	Jt219.cf	5	10	8	5		Xfer (protocol recorded)
220	Jt220.cf	4	5	9	3		Xfer (protocol recorded)
221	Jt221.cf	2	7	4	11		Xfer
222	Jt222.cf	3	5	3	8		Xfer
223	Jt223.cf	4	12	X	X	HF1, 50% @ 1min +PH (cf. #97)	Xfer; Fault1 (prtcl. recorded)
224	Jt224.cf	6	7	7	2	VB blockage @ 8min +PH (cf. #187)	Xfer; Fault2 (prtcl. recorded)
							Test Day #6

APPENDIX B1:

Pre-experimental materials

INTRODUCTION TO THE EXPERIMENT

This experiment addresses the problem of how to design computer interfaces for complex industrial systems, such as power plants. As a subject in this experiment, you will be asked to work with one of two different interfaces for a thermal-hydraulic system to be described below. There will be a total of about 100 different sessions, most of which will consist of two trials each. In this session, you will be introduced to the system that you will be controlling, and you will be given a series of off-line tasks to perform to evaluate your knowledge of thermal hydraulics and your understanding of the system you will be using. Over the course of the rest of the experiment you will be given time to practice controlling the system in the context of various tasks. Occasionally a session will be used to administer off-line tests instead of conducting practice trials. Also, during some trials you will be asked to provide a verbal protocol describing your thought processes as you control the system. These trials will be videotaped.

You are **highly** encouraged to offer any opinions, questions, comments, suggestions, or any other information particularly concerning your conception of DURESS and any insights you may have as you learn about the system. Please try to keep this in mind throughout the experiment. Nothing is too insignificant to mention!

You will now be asked to read a technical description of the thermal-hydraulic system that will be used in this experiment. After you have finished reading this description, you will be given a questionnaire to evaluate your knowledge of thermal-hydraulics. You may consult the technical description at any time while answering the questions.

CONSENT TO TAKE PART IN RESEARCH

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

Research on Factors Influencing Human Cognitive Behaviour (I)

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 videotapes of verbal protocol trials to be given to me or destroyed.

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

Name:_____

Signature:_____

Address:_____

_____

Date:_____

Demographic Questionnaire

SUBJECT #: _____

AGE: _____ SEX: _____

1 What academic year are you in? _____

2 What is your major area of study? _____

3 What is your minor area of study? _____

4 If you are a graduate student, what areas of study were your previous degrees in?

_____

5 How many university level physics courses have you taken? (Include both graduate and undergraduate level courses).

_____

6 How many university level courses in thermodynamics and/or thermal-hydraulics have you taken? (Include both graduate and undergraduate level courses, but do not include courses counted in question 4).

_____

7 Briefly describe your current and past research interests (if any) and/or work responsibilities. (use back if necessary).

_____

_____

_____

_____

Technical Description of DURESS II

DURESS II (DUal REservoir System Simulation) is a thermal-hydraulic process simulation that will be used in this experiment. This description is meant to get you familiar with the functional characteristics of the system. The physical structure of DURESS II is illustrated in the accompanying figure. The system consists of two redundant feedwater streams that can be configured to supply water to two reservoirs. The goals are to keep each of the reservoirs at a prescribed temperature (40 °C and 20 °C), and to maintain enough water in each reservoir to satisfy each of the current demand flow rates, which are externally determined. To satisfy these system goals, there are eight valves, two pumps, and two heaters. DURESS II has been modeled to be consistent with the laws of physics (e.g., the conservation laws). However, several simplifying assumptions have been made (see below). A more detailed description of the various system components follows.

Source of Water

As shown in the figure, the water that feeds into DURESS II is obtained from 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 consists of one pump and two valves. In addition, there is also one valve to control output. The two streams are functionally identical, each having a capacity for attaining a maximum flowrate of 10 units/sec. Thus, the combined feedwater supply capacity of the two streams is 20 units/sec. Each feedwater stream can be configured to supply water to either, both, or neither of the two reservoirs.

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

Each of the 8 valves is identical. The valve settings have a linear range from 0 (completely closed) to 10 (all the way open). The maximum flowrate through any valve is 10 units/sec. It is assumed that the valve settings directly specify the flowrates (or the flowrate ratios when appropriate) rather than the flow resistances.

Pumps

The 2 pumps 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/sec.

Heaters

The 2 heaters are also functionally identical. They have a continuous control setting ranging from 0 (off) to 10 (maximum heat flow). Since the water is coming in at 10 °C, both reservoirs require a heater to attain their respective temperature setpoints (20 °C and 40 °C).

Reservoirs

The 2 reservoirs are of identical size. 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 determines the desired output flowrate for each reservoir. Thus, 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/sec (no demand) to 20 units/sec (full demand), with the added constraint that the combined demands from the 2 reservoirs does not exceed 20 units/sec, since this is the combined capacity of the two feedwater streams.

LIST OF VARIABLE NAMES

ABBREVIATIONS: fws = feedwater stream res. = reservoir

Energy Variables

E1 - total Energy stored in res. 1
E2 - total Energy stored in res. 2
EI1 - Energy Input flowrate for res. 1
EI2 - Energy Input flowrate for res. 2
EO1 - Energy Output flowrate for res. 1
EO2 - Energy Output flowrate for res. 2

Flowrates (Water and Heat)

FPA - Flowrate from pump PA
FPB - Flowrate from pump PB
FVA - Flowrate from valve VA
FVB - Flowrate from valve VB
FA1 - Flowrate from valve VA1
FB1 - Flowrate from valve VB1
FA2 - Flowrate from valve VA2
FB2 - Flowrate from valve VB2
FH1 - Flowrate from heater HTR1
FH2 - Flowrate from heater HTR2
FA3 - Flowrate from valve VA3
FB3 - Flowrate from valve VB3

Heater Settings

HTR1 - setting for Heater of res. 1
HTR2 - setting for Heater of res. 2

Mass Variables

D1 - Demand (output) flowrate for res. 1
D2 - Demand (output) flowrate for res. 2
MI1 - Mass Input flowrate for res. 1
MI2 - Mass Input flowrate for res. 2
V1 - Volume of res. 1
V2 - Volume of res. 2

Pump Settings

PA - setting of Pump in fws A
PB - setting of Pump in fws B

Temperature Variables

T1 - Temperature of res. 1
T2 - Temperature of res. 2

Valve Settings

VA - setting of initial Valve in fws A
VB - setting of initial Valve in fws B
VA1 - setting of Valve 1 in fws A
VB1 - setting of Valve 1 in fws B
VA2 - setting of Valve 2 in fws A
VB2 - setting of Valve 2 in fws B
VA3 - setting of Valve 3 in fws A
VB3 - setting of Valve 3 in fws B

Pre-Test Questionnaire

SUBJECT #: _____

The following 20 questions are designed to assess your knowledge of thermal-hydraulics before the experiment begins. Each question has five multiple choice answers, only one of which is correct. You are allowed to consult the technical description of DURESS II and the accompanying diagram of DURESS II at any time, if you wish. Read each question carefully and use only the information that is provided in the question to select your response. Do not make any assumptions about the state of the system that are not explicitly stated in the question. If you think that, based solely on the information provided, it is not possible to select a unique correct response (i.e., if there is not enough information provided to answer the question), then select multiple choice option (e) Indeterminate. Please select only one answer for each question. You may use scrap paper for calculations, if you wish. All numerical values are rounded off to one decimal place. You have 30 minutes to complete the questionnaire.

Variable Definitions:

VA, VA1, VA2, VB, VB1, VB2 - **Valve Settings**

T1, T2 - **Water Temperatures**

PA, PB - **Pump Settings**

V1, V2 - **Reservoir Volumes**

H1, H2 - **Heater Settings**

E1, E2 - **Total Reservoir Energy**

IN1, IN2 - **Input Flowrates to Reservoirs**

D1, D2 - **Demand Flowrates**

An F in front of a label refers to the flow through that component (e.g., FA2 is the flowrate through valve VA2).

1. If the component settings are PA = ON, VA = 10, VA1 = 8, VA2 = 4, then what will the flows through the three valves in this feedwater stream be?

a) FA = 10, FA1 = 8, FA2 = 4
b) FA = 10, FA1 = 6.7, FA2 = 3.3
c) FA = 12, FA1 = 8, FA2 = 4
d) FA = 8, FA1 = 5.3, FA2 = 2.7
e) Indeterminate

2. If the demand (D2) is zero, adding more water to reservoir 2 will always:

a) increase the volume (V2)
b) decrease the temperature (T2)
c) increase the total energy (E2)
d) both a and c
e) both a and b

3. If there is no water entering reservoir 1 (IN1 = 0), a decrease in the demand (D1) will always:

a) increase the temperature (T1)
b) decrease the absolute value of the rate of change of volume (V1)
c) increase the absolute value of the rate of change of volume (V1)
d) both a and c
e) both a and b

4. If the component settings are PB = ON, VB = 9, VB1 = 8, VB2 = 8, then what will the flows through the three valves in this feedwater stream be?

a) FB = 9, FB1 = 4.5, FB2 = 4.5
b) FB = 9, FB1 = 8, FB2 = 8
c) FB = 8, FB1 = 8, FB2 = 8
d) FB = 16, FB1 = 8, FB2 = 8
e) Indeterminate

5. If the system is not yet at steady state and if volume (V1) is being held constant (input = output), increasing the heater setting (H1) will:

a) result in a higher steady state temperature (T1) than if the heater setting (H1) was not increased
b) not change the steady state temperature (T1), but will achieve that temperature more quickly than if the heater setting (H1) was not increased
c) change the specific heat capacity of the reservoir
d) decrease the absolute value of the rate of change of temperature (T1)
e) Indeterminate

6. If the flows through are VA1, VA2, VB1, and VB2 are 8, 2, 7, and 3, respectively, then the flow IN1 will be:

a) 15
b) 10
c) 20
d) 5
e) Indeterminate

7. If the component settings are PB = ON, VB = 2, VB1 = 7, VB2 = 0, then what will the flows through the three valves in this feedwater stream be?

a) FB = 2, FB1 = 7, FB2 = 0
b) FB = 7, FB1 = 7, FB2 = 0
c) FB = 2, FB1 = 2, FB2 = 0
d) FB = 7, FB1 = 0, FB2 = 7
e) Indeterminate

8. If the system is at steady state with the heater (H1) on at a fixed setting, increasing the input flowrate (IN1) will:

a) increase the temperature (T1)
b) decrease the temperature (T1)
c) not change the temperature (T1)
d) affect the density parameter
e) Indeterminate

9. If the system is at steady state with the heater (H2) on at a fixed setting, decreasing the throughput while holding volume (V2) constant will:

a) decrease the steady state temperature (T2)
b) increase the steady state temperature (T2)
c) change the specific heat capacity
d) not affect the steady state temperature (T2)
e) Indeterminate

10. With the system at steady state and the heater (H1) on at a fixed setting, the steady state temperature (T1) will be X degrees. If these same conditions are reproduced but with a smaller volume (V1), the new steady state temperature would be:

a) the same (i.e., X)
b) greater than X
c) less than X
d) it depends on the exact value of the heater setting
e) Indeterminate

11. If the component settings are PB = ON, VB = 8, VB1 = 2, VB2 = 3, then what will the flows through the three valves in this feedwater stream be?

a) FB = 8, FB1 = 3.2, FB2 = 4.8
b) FB = 3, FB1 = 2, FB2 = 3
c) FB = 5, FB1 = 2, FB2 = 3
d) FB = 8, FB1 = 2, FB2 = 3
e) Indeterminate

12. If all other parameters are held constant, increasing the input flowrate (IN1) will always:

a) change the thermal expansion coefficient
b) decrease the temperature (T1)
c) not affect the temperature (T1)
d) increase the temperature (T1)
e) Indeterminate

13. If the component settings are PB = ON, VB = 7, VB1 = 3, VB2 = 4, then what will the flows through the three valves in this feedwater stream be?

a) FB = 7, FB1 = 4.3, FB2 = 5.7
b) FB = 3, FB1 = 3, FB2 = 4
c) FB = 2, FB1 = 3, FB2 = 4
d) FB = 7, FB1 = 3, FB2 = 4
e) Indeterminate

14. If the system is at steady state, increasing the input flowrate (IN1) will:

a) increase the volume (V1) and decrease the total energy (E1)
b) increase the volume (V1) and not change the total energy (E1)
c) decrease the absolute value of the rate of change of volume
d) increase the volume (V1) and increase total energy (E1)
e) Indeterminate

15. If the component settings are PB = ON, VB = 2, VB1 = 3, VB2 = 9, then what will the flows through the three valves in this feedwater stream be?

a) FB = 12, FB1 = 3, FB2 = 9
b) FB = 2, FB1 = 0.5, FB2 = 1.5
c) FB = 10, FB1 = 2.5, FB2 = 7.5
d) FB = 2, FB1 = 3, FB2 = 9
e) Indeterminate

16. If the component settings are PA = ON, VA = 6, VA1 = 6, VA2 = 6, then what will the flows through the three valves in this feedwater stream be?

a) FA = 10, FA1 = 5, FA2 = 5
b) FA = 12, FA1 = 6, FA2 = 6
c) FA = 6, FA1 = 6, FA2 = 6
d) FA = 6, FA1 = 3, FA2 = 3
e) Indeterminate

17. For fixed initial conditions with the heater (H2) on at a fixed setting, a steady state temperature (T2) of Y° is attained. If the same conditions were reproduced but with a larger volume (V2), then:

a) a different steady state temperature (T2) would be reached in the same time
b) the same steady state temperature (T2) would be reached but it would take longer
c) a different steady state temperature (T2) would be reached and it would take longer
d) the same steady state temperature (T2) would be reached in the same time
e) Indeterminate

18. If the component settings are PA = ON, VA = 10, VA1 = 0, VA2 = 6, then what will the flows through the three valves in this feedwater stream be?

a) FA = 6, FA1 = 0, FA2 = 6
b) FA = 10, FA1 = 4, FA2 = 6
c) FA = 10, FA1 = 0, FA2 = 6
d) FA = 10, FA1 = 0, FA2 = 10
e) Indeterminate

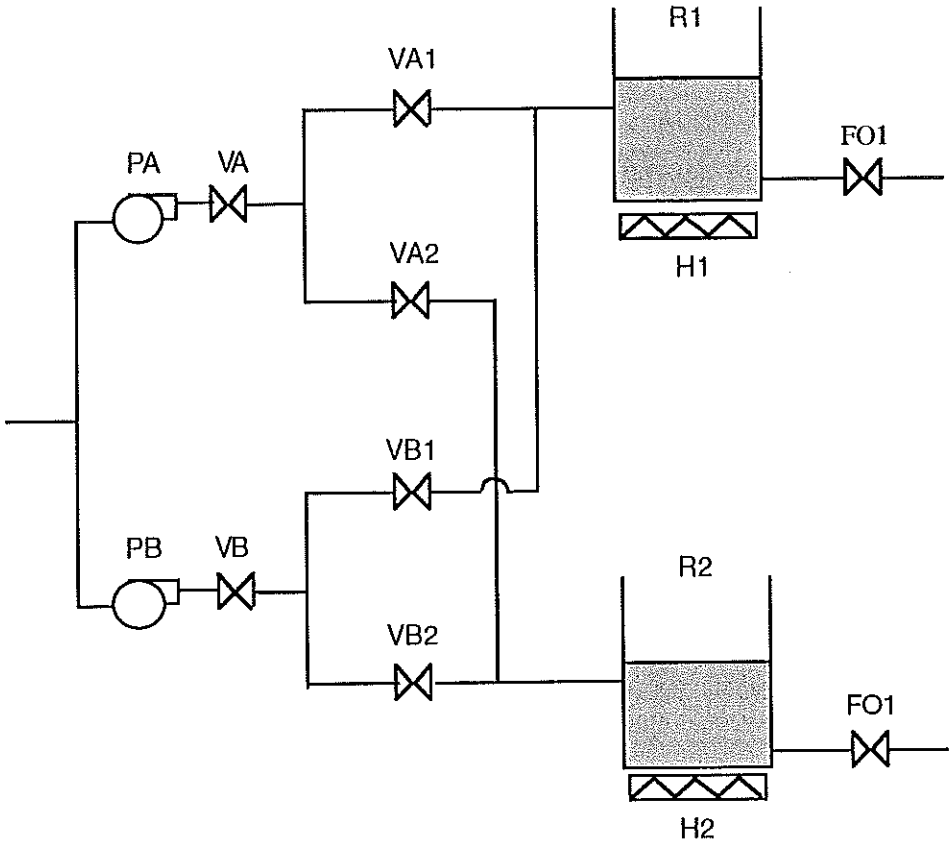
19. If the component settings are PB = OFF, VB = 10, VB1 = 10, VB2 = 10, then what will the flows through the three valves in this feedwater stream be?

a) FB = 10, FB1 = 0, FB2 = 0
b) FB = 10, FB1 = 10, FB2 = 10
c) FB = 10, FB1 = 5, FB2 = 5
d) FB = 0, FB1 = 0, FB2 = 0
e) Indeterminate

20. If the component settings are PA = ON, VA = 8, VA1 = 3, VA2 = 3, then what will the flows through the three valves in this feedwater stream be?

a) FA = 6, FA1 = 4, FA2 = 4
b) FA = 8, FA1 = 3, FA2 = 3
c) FA = 6, FA1 = 3, FA2 = 3
d) FA = 8, FA1 = 4, FA2 = 4
e) Indeterminate

Diagram of DURESS II



Scoring Key

1. B
2. D
3. B
4. A
5. A
6. A
7. C
8. B
9. B
10. A
11. C
12. E
13. D
14. D
15. B
16. D
17. B
18. A
19. D
20. C

Experimental Procedure: EID Interface

['ipaste P+F.rgb' to get EID interface]

EID Interface

This is the interface 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 in thermometer T0. The pump settings (e.g., PB) are discrete (either ON or OFF), and are therefore directly labelled on the pumps themselves. The valve settings (e.g., VB) range from 0 to 10 and are indicated by the small yellow, triangular pointers on the respective scales. The flowrates in each feedwater stream (e.g., FPA, FVA, FA1, FA2) range from 0 to 10 and are indicated by yellow bars next to the respective components. The output valve (e.g. FO1) is below the mass balance graphic and is indicated by a yellow triangle. The flowrate for this output valve (e.g. VO1) is shown by the yellow bar on the bottom of the mass balance graphic (for explanation, see below). The heater settings (e.g., HTR2) range from 0 to 10, with a red triangle as an indicator. The heating rates are displayed next to the heater settings as red bars. Note that the heater rate and heater setting scales 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 (e.g., MI1 for the mass and EI1 for the energy), the inventories on the side (e.g., V1 for volume, or mass, and E1 for energy), and the outputs at the bottom (e.g., MO1 for demand, or mass, and EO1 for energy). The energy inputs (EI1 and EI2) are partialled out according to the two contributors, indicated by the flow lines. Thus, the energy added by the feedwater is shown as the yellow bar, while the energy added by the heater is shown as the red bar. The energy output (e.g., EO1) is proportional to the product of temperature (T1) and demand (MO1), as indicated by the 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 (i.e., output greater than input), then it is easy to visualize the consequence, namely that the volume should be decreasing. Thus, the slope of the line represents the rate at which the mass (or energy) inventory is changing. If input equals output, then the line would be perpendicular, 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. The height of the horizontal bar that emanates from the current volume level line should always accompany any change in volume (i.e., the bar will always be at the same height as the water level, V1 or V2). The thick diagonal line in the center 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 center display. For example, if volume increases, the horizontal line goes up, causing the diagonal to rotate counterclockwise, 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 vertical area on the two temperature scales (T1 and T2, respectively). Similarly, the upper and lower limits around the output goals are shown as green vertical areas on the output flowrate meter.

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

[Enter 0 to exit program]

Procedure

During this experiment, you will be directly controlling DURESS. Each trial consists of a "scenario" of DURESS' behavior. During some scenarios, the system will exhibit a normal pattern of behavior following the description of DURESS that you read before. During other scenarios, however, faults or disturbances may occur during operation. Please keep in mind, however, that for this experiment, there will not be any simulated sensor failures.

There are four different trial types which you may encounter while controlling DURESS. These are as follows:

1) Start-Up. For this task, you will be presented with a shut-down system and will be asked to bring the system on-line to steady-state defined by a desired setpoint consisting of temperature and demand goals.

2) Tuning to New Setpoints. In this type of task, you need to bring the system from an on-line, steady-state initial condition to a pair of new steady-state demand setpoints, which will be defined by the experimenter.

3) Shut-Down. In this type of task you are required to bring the system from an on-line, steady-state condition to an off-line condition.

4) Disturbance Management. In the event of a fault, your goal is to detect, diagnose, and compensate for that observed fault.

For each trial, it is your task to ensure that temperature and output demands are being met. "Steady-state" is defined by the case when the system demands (temperature and output) have been met for five (5) consecutive minutes. In the case of a fault, you are responsible for detecting and diagnosing that fault and, most importantly, compensating for that fault in order to continue to meet the prescribed demands.

Experimental Procedure: P&ID Interface

['ipaste P.rgb' to get P&ID interface]

P & ID Interface

This is the interface 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 (e.g., PB) are discrete (either ON or OFF), and are therefore directly labelled on the pumps themselves. The valve settings (e.g., VB) range from 0 to 10 and are indicated by the small yellow triangular pointers on the respective scales. The demands (D1, D2) can range from 0 to 20 and are indicated by the green areas within the outlet valve indicator (e.g. VO1). Volume (V1, V2), can range from 0 to 100 and is indicated by the blue area and by the vertical scale on the side of each reservoir. The output temperature (T1, T2) can range from 0 to 50. The heater settings (e.g., HTR2) also range from 0 to 10 and are indicated by small, red triangular pointers. 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). Similarly, the upper and lower limits around the output goals are shown as green areas on the output valve scales.

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

[Enter 0 to exit program]

Procedure

During this experiment, you will be directly controlling DURESS. Each trial consists of a "scenario" of DURESS' behavior. During some scenarios, the system will exhibit a normal pattern of behavior following the description of DURESS that you read before. During other scenarios, however, faults or disturbances may occur during operation. Please keep in mind, however, that for this experiment, there will not be any simulated sensor failures.

There are four different trial types which you may encounter while controlling DURESS. These are as follows:

1) Start-Up. For this task, you will be presented with a shut-down system and will be asked to bring the system on-line to steady-state defined by a desired setpoint consisting of temperature and demand goals.

2) Tuning to New Setpoints. In this type of task, you need to bring the system from an on-line, steady-state initial condition to a pair of new steady-state demand setpoints, which will be defined by the experimenter.

3) Shut-Down. In this type of task you are required to bring the system from an on-line, steady-state condition to an off-line condition.

4) Disturbance Management. In the event of a fault, your goal is to detect, diagnose, and compensate for that observed fault.

For each trial, it is your task to ensure that temperature and output demands are being met. "Steady-state" is defined by the case when the system demands (temperature and output) have been met for five (5) consecutive minutes. In the case of a fault, you are responsible for detecting and diagnosing that fault and, most importantly, compensating for that fault in order to continue to meet the prescribed demands.

Verbal Protocol Instructions

Notice that a video camera is set up near the computer. This camera will be used today and during various other sessions to video-record the experiment. Please note that the video being recorded is for the experimenter's use only, and these data will be kept strictly confidential. In addition, you yourself will not be video-taped. Only your voice and the computer monitor will appear on the tape.

For the video-recording sessions, you will be wearing a small, high-fidelity microphone attached to your shirt, so there is no need to speak directly into the mic.

While you are being video recorded, we ask that you think aloud about what you are doing while operating the system. Some questions we are trying to answer by doing this are:

- How is the system behaving? Why?
- What are you thinking about during the session?
- When you make a control input, why did you do it?
- What effect do you think a certain control input will have on the system?

After the video tapes are recorded the experimenter will review the tapes to try to get a feel for what you were thinking as you controlled the system. This is why the computer monitor is being recorded. The combined information of what is happening on the computer monitor and your verbalized thought processes may provide the experimenter with some valuable insights as to how you are controlling the system.

At first, this verbalization of thoughts will seem awkward and slightly unnatural. During this first session, please feel free to ask the experimenter *any* questions you may have about the type of information you are verbalizing. I urge you to be as verbal as possible so that a better understanding of the session can be obtained.

Do you have any questions for the experimenter?

APPENDIX B2:

Test-day Materials

Procedure: categorization of components

In this procedure you will be given 14 cards showing names and pictures of the individual components of DURESS. Your task is to sort these cards into piles based on whatever criteria that you feel are appropriate. Ignore the specific settings of the components - they aren't important. The accompanying table explains the component codes - you may refer to it as often as you like. Please notify the experimenter when you are finished.

Component designations

HTR1	Heater 1
HTR2	Heater 2
PA	Pump A
PB	Pump B
RES1	Reservoir 1
RES2	Reservoir 2
VA	Valve A
VA1	Valve A1
VA2	Valve A2
VB	Valve B
VB1	Valve B1
VB2	Valve B2
VO1	Output Valve 1
VO2	Output Valve 2

Procedure: categorization of demand pairs

In this procedure you will be given a number of cards with pairs of numbers printed on them representing the demands for the upper and lower reservoirs in a hypothetical DURESS scenario. Your task is to sort these demand pairs into a number of groups based on whatever **one** specific criterion you feel is the most natural.

As an analogy, imagine that you are in the fruit section of a supermarket and that your task is to sort all of the various fruits into categories based on **one** specific criterion of your choosing. You may choose to sort them on the basis of colour, in which case the strawberries, cherries, red apples, etc will be in one group, while bananas, lemons, and other yellow fruits will make up another group, and so on. Alternatively, you may choose to sort the fruit based on variety, in which case all of the apples will be in one group, all of the oranges will be in another, all of the bananas will be in another, and so on.

The important thing is that you choose one and only one specific criterion (e.g. colour or variety) and stick to it as you perform the sorting task. Please ask the experimenter if you have any questions about this procedure. Also, please be sure to notify the experimenter when you are finished.

Demand pairs (D1,D2):

(4,2),(11,6),(8,4),(9,8),(12,6),(12,5),(9,1),(6,3),(10,5),(11;3),(8,3)
(3,3),(2,2),(8,8),(6,6)

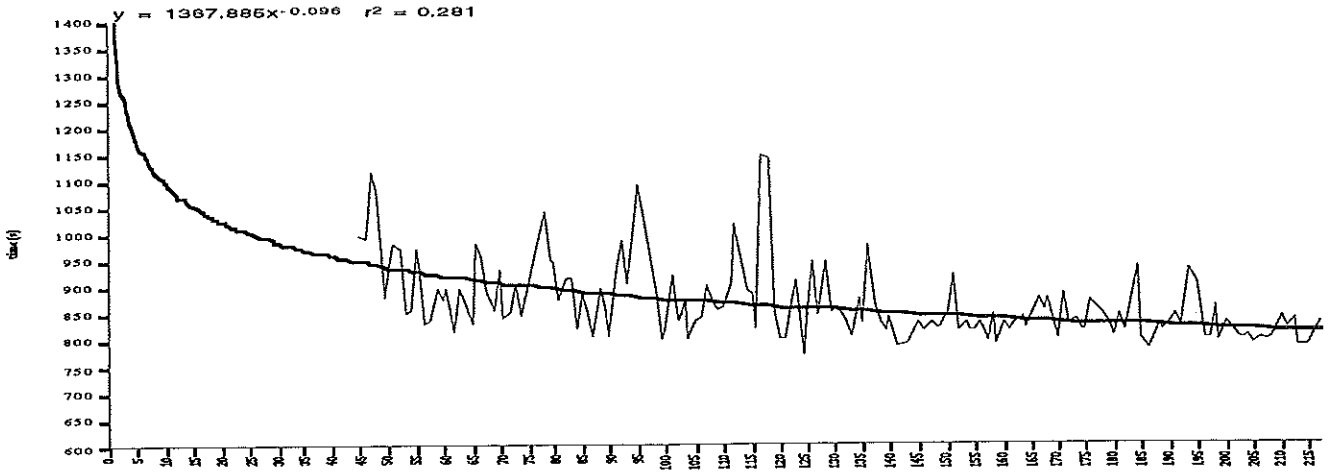
Procedure: control recipe

In this procedure, your task is to write out a set of instructions for performing a start up of DURESS (i.e. bring the system from an "off-line" condition 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)

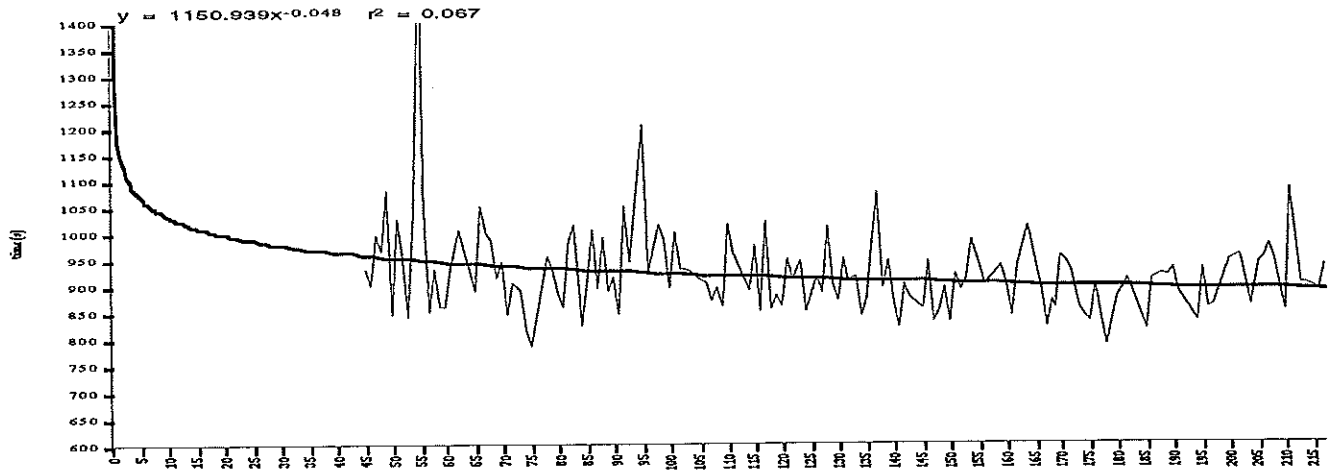
APPENDIX C:

Learning Curves for Non-fault Trials

IS: Total Time



AS: Total Time



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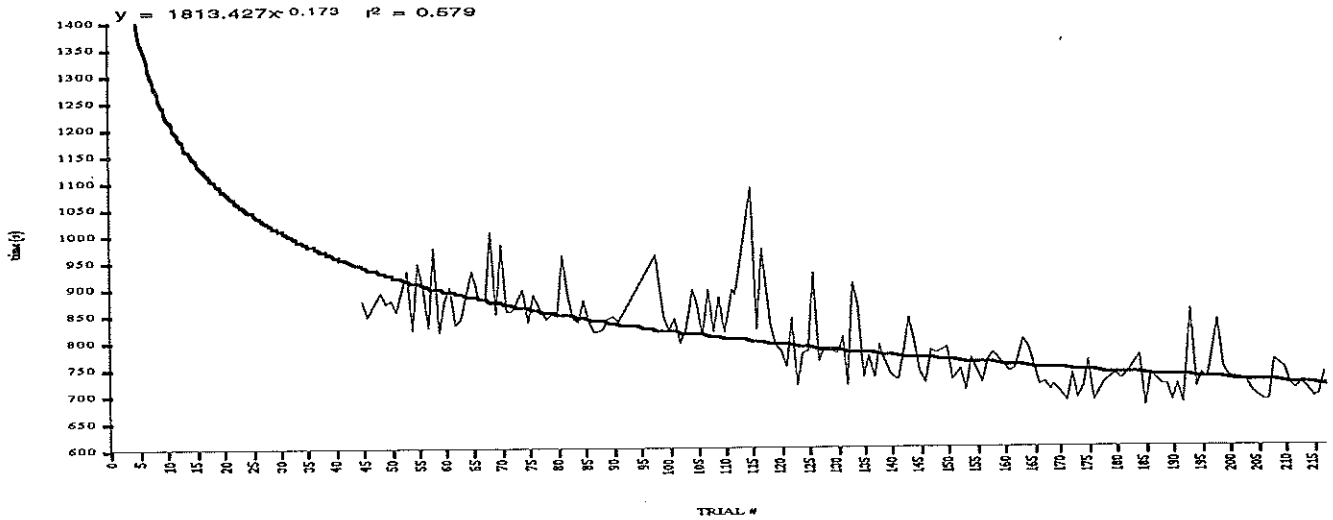

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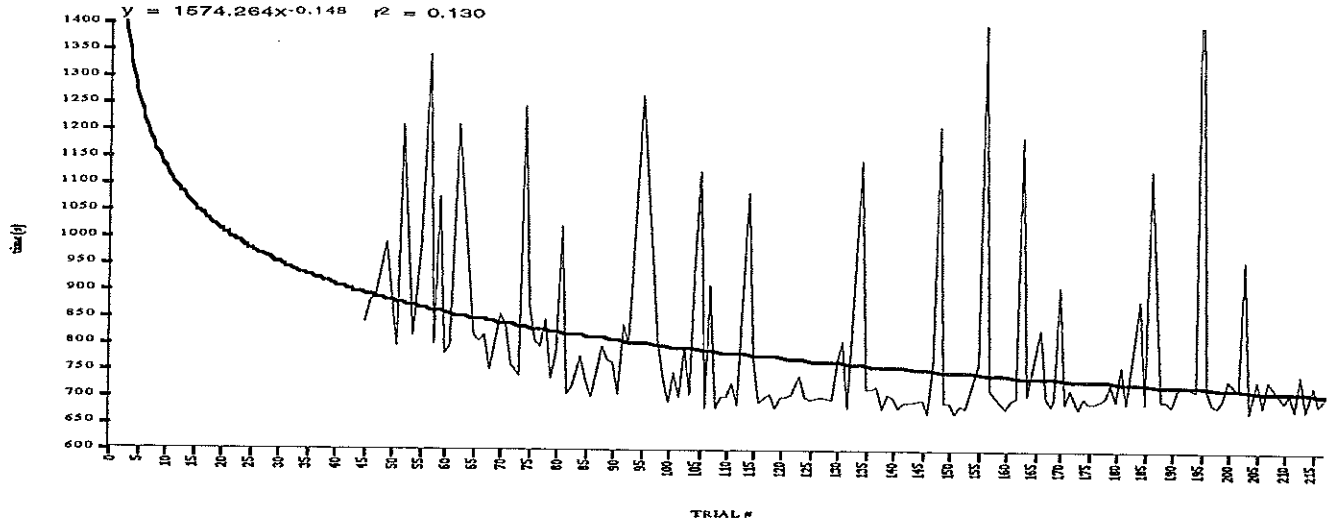
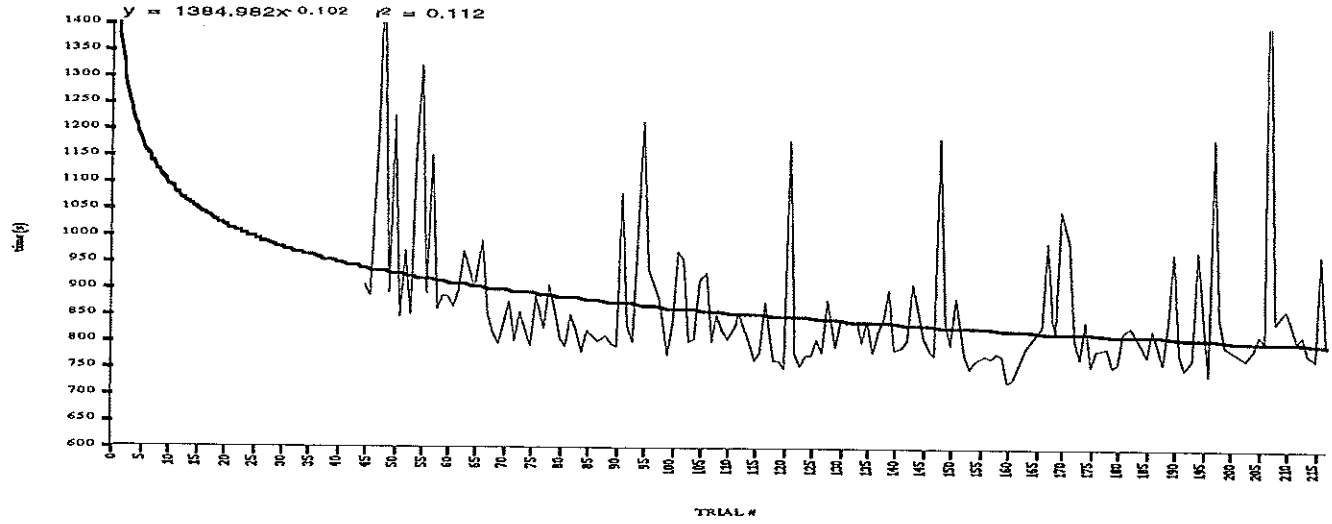
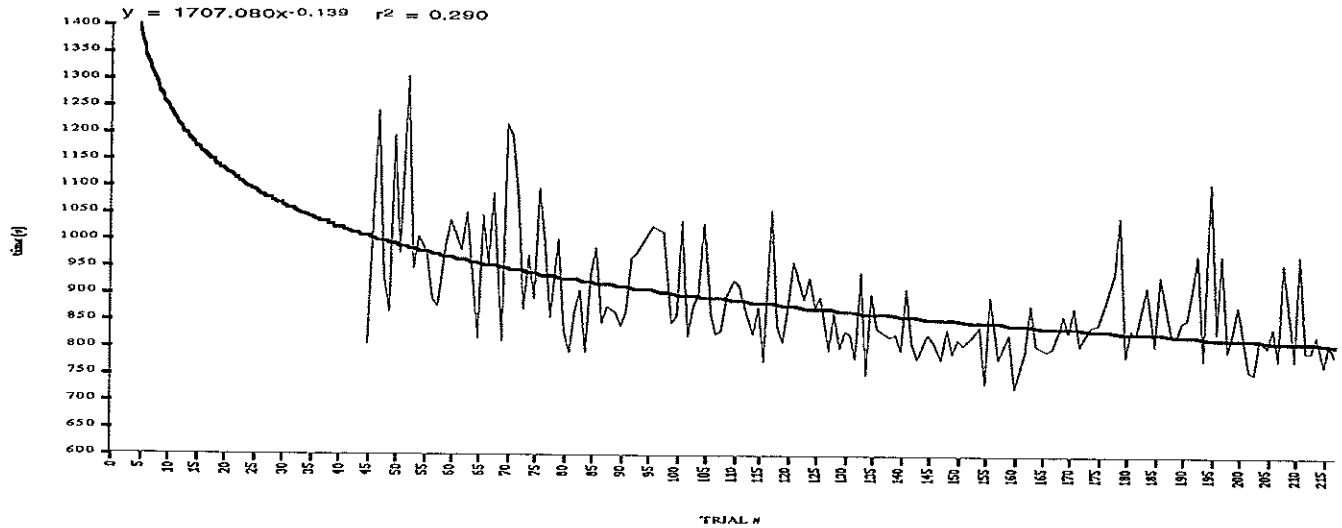


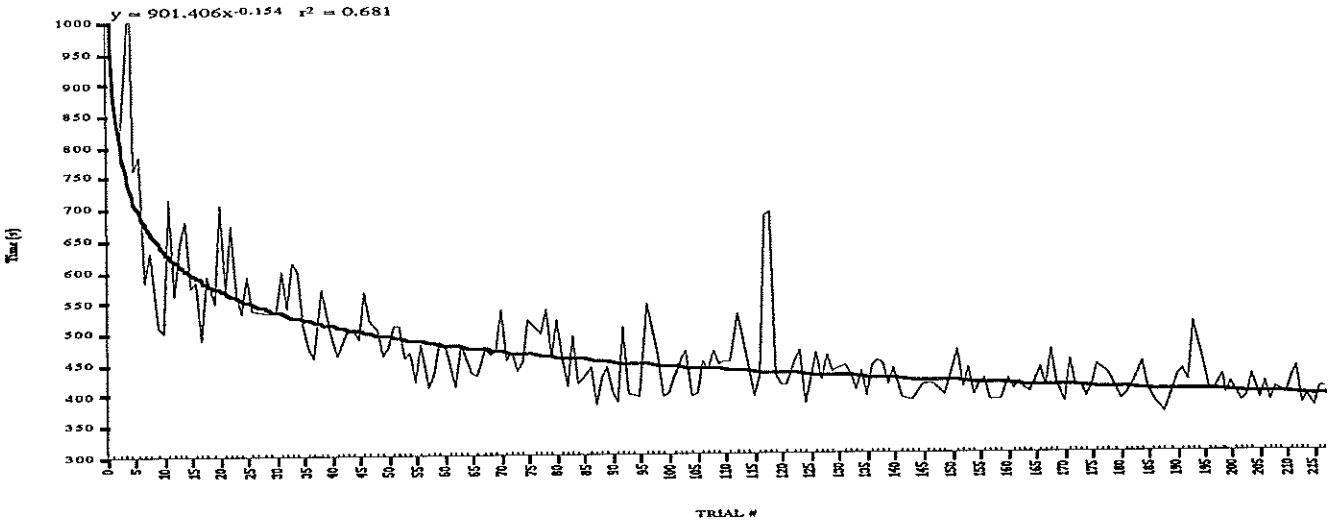
WL: Total Time



ML: Total Time



IS: Start Up



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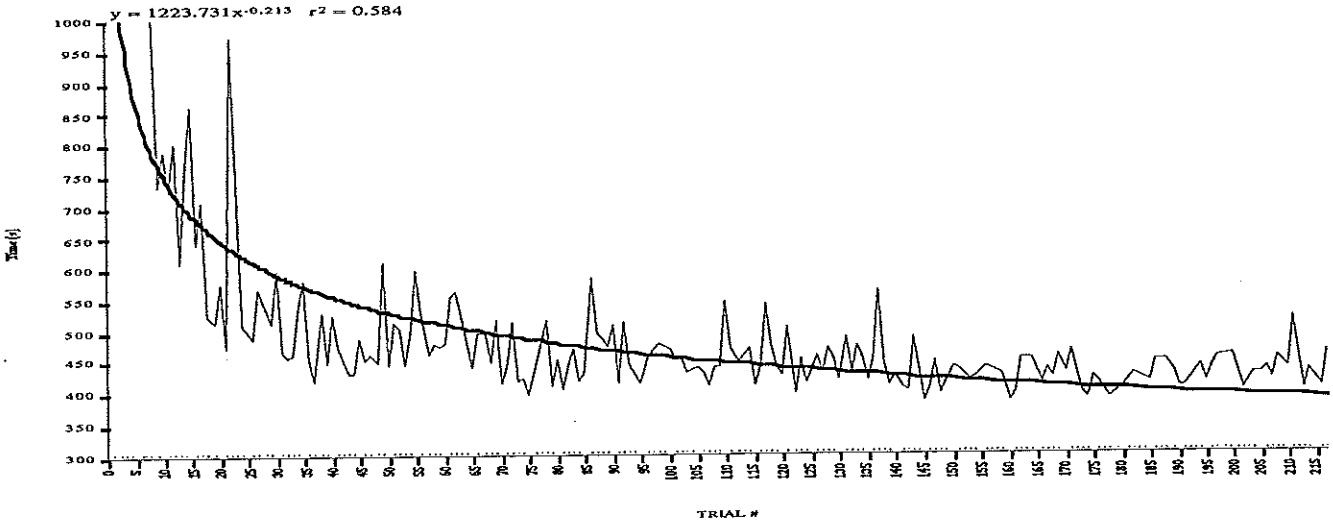

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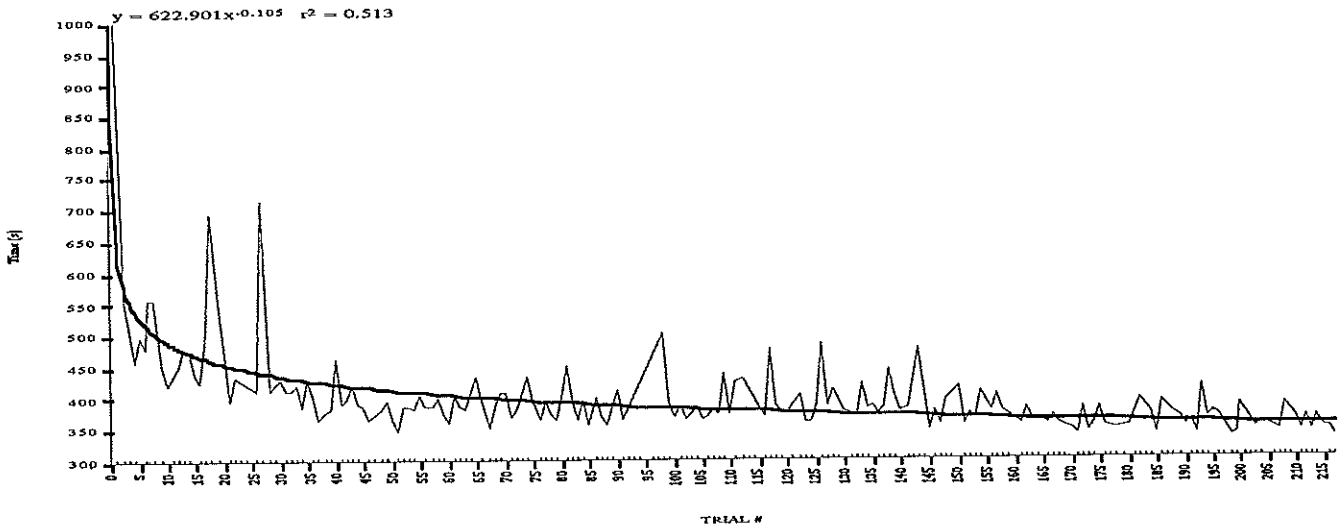
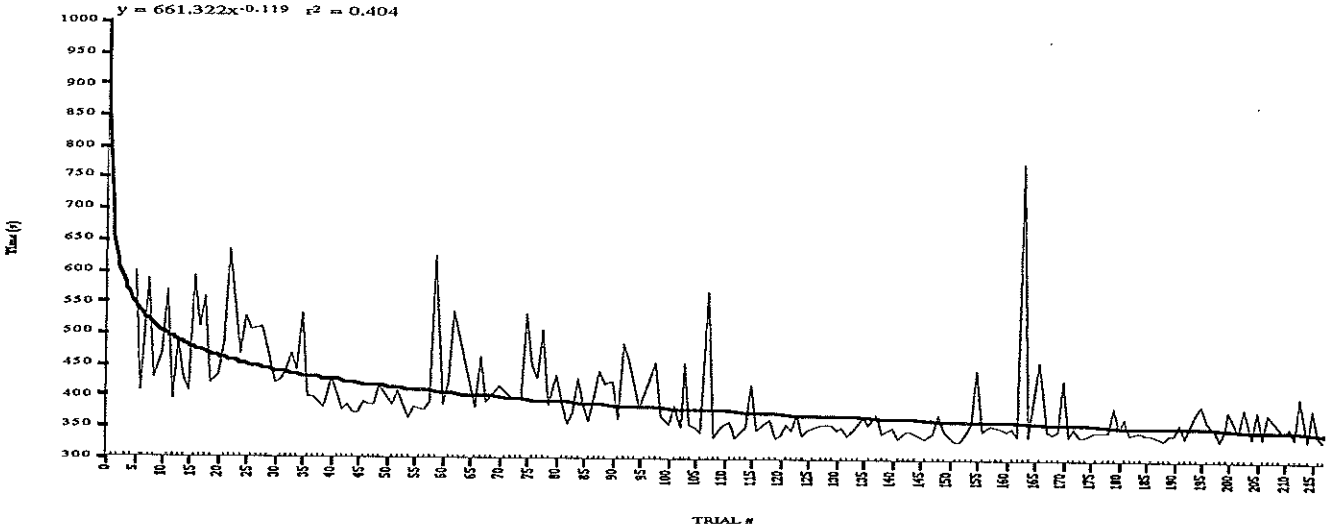
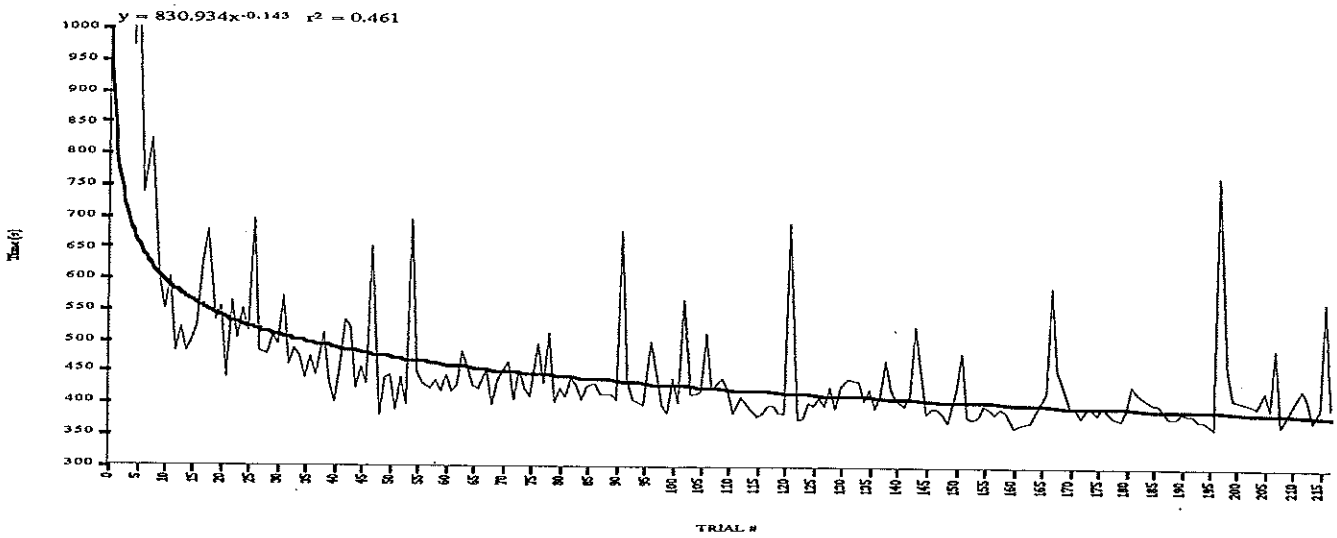


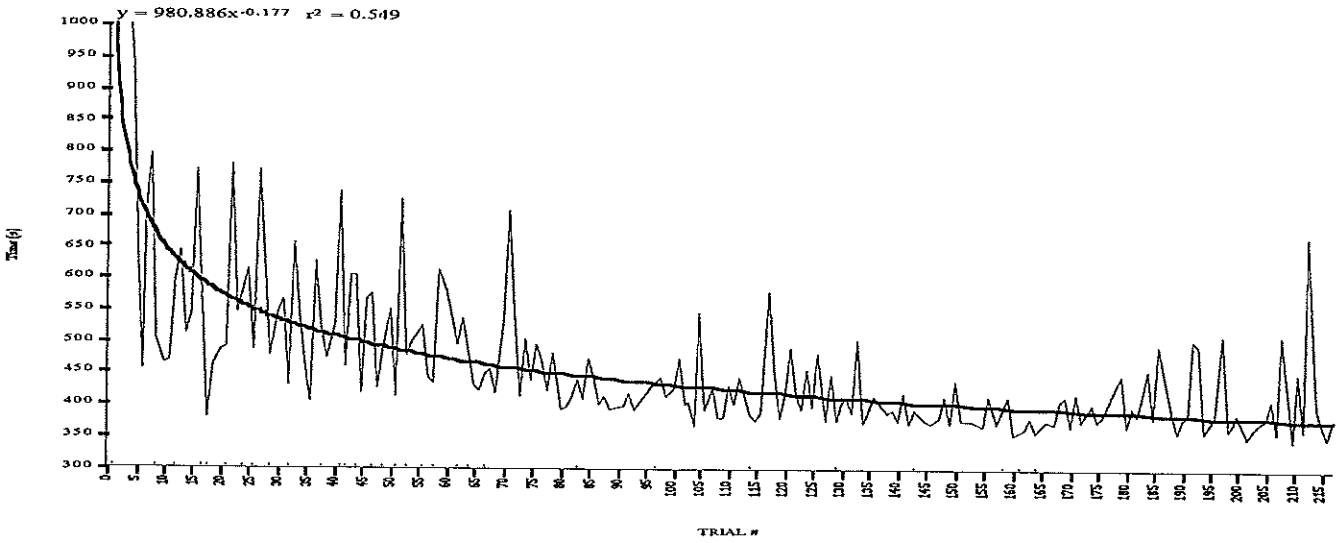
TL: Start Up



WL: Start Up



ML: Start Up



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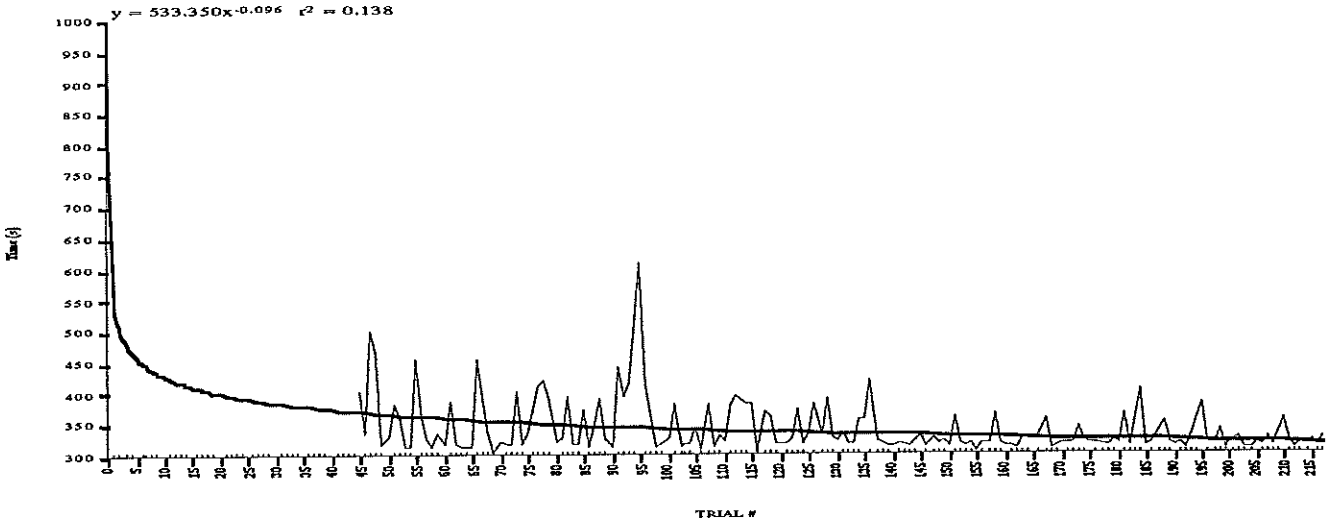

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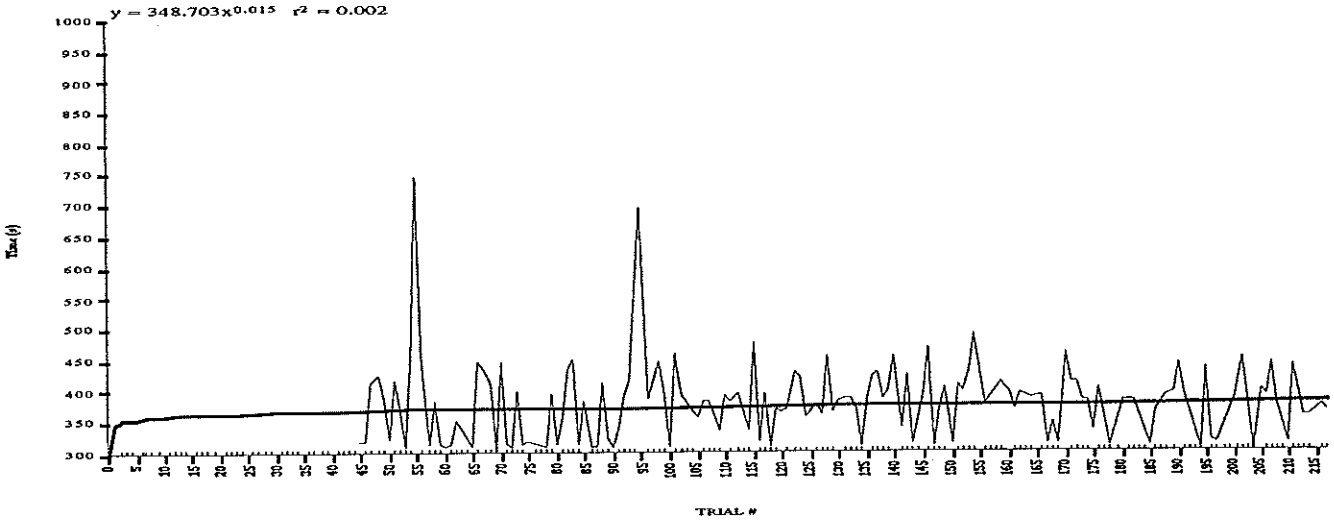

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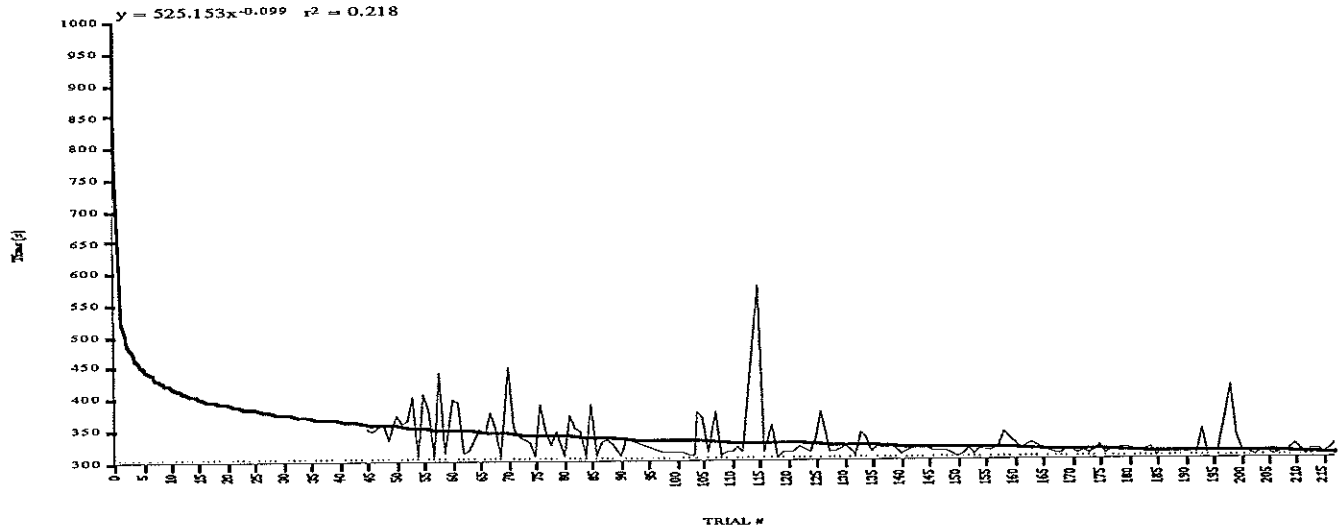

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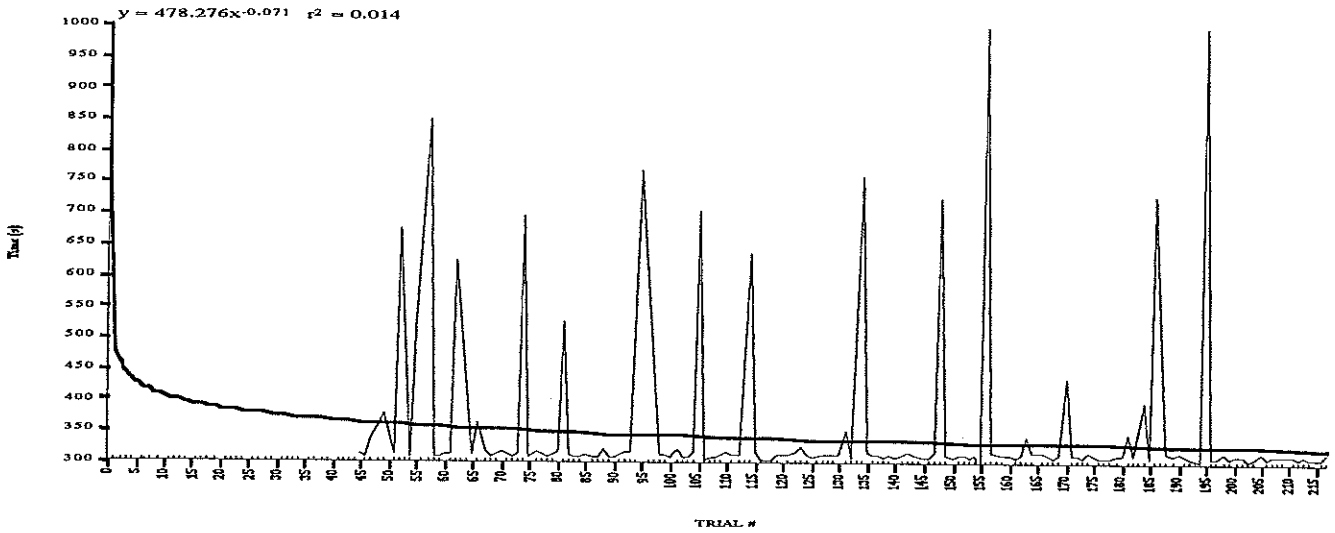

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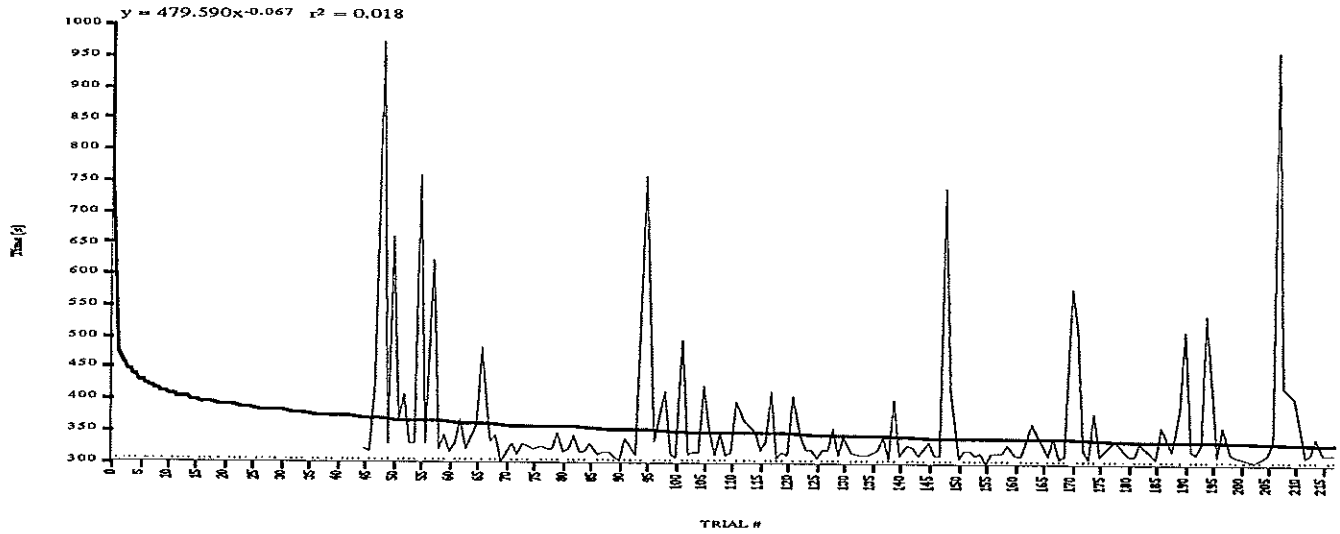

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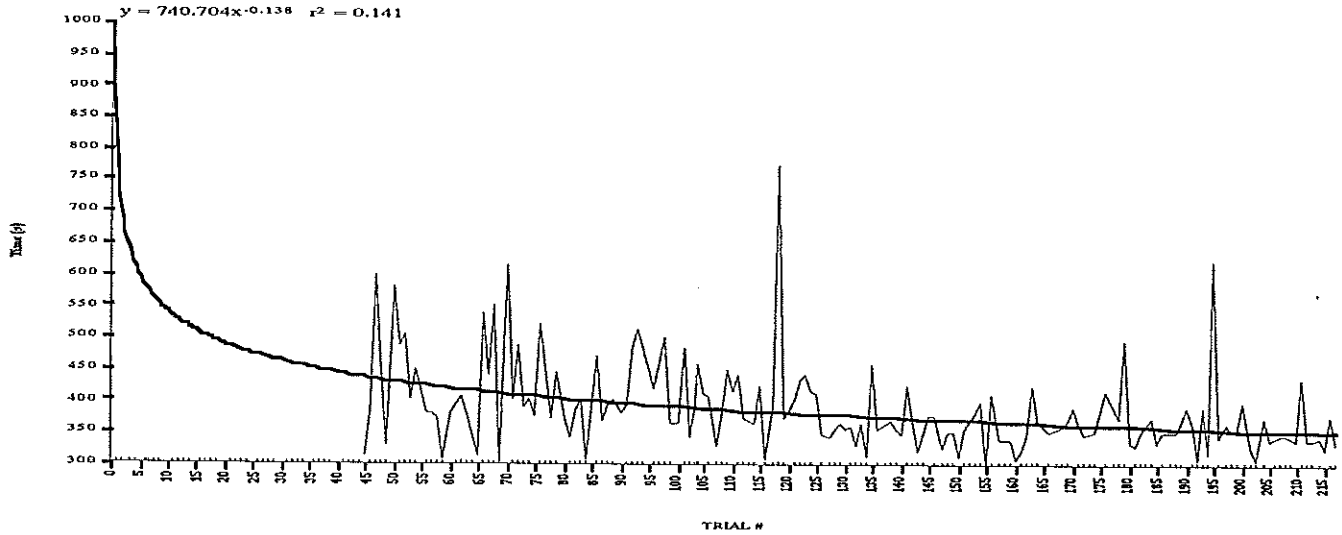
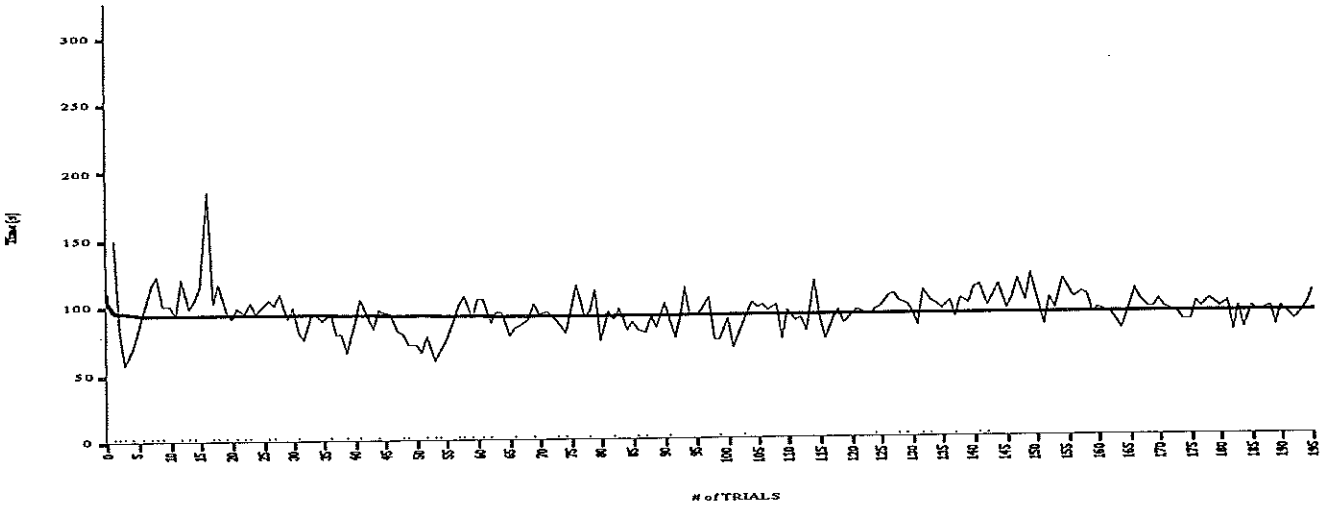


IS: SHUT DOWN



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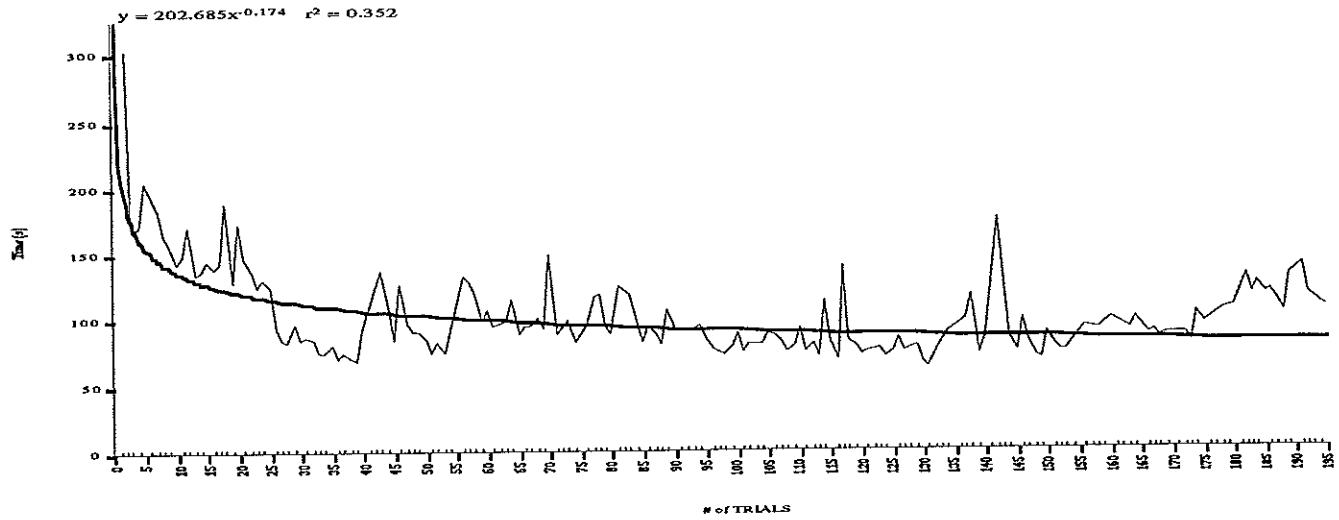

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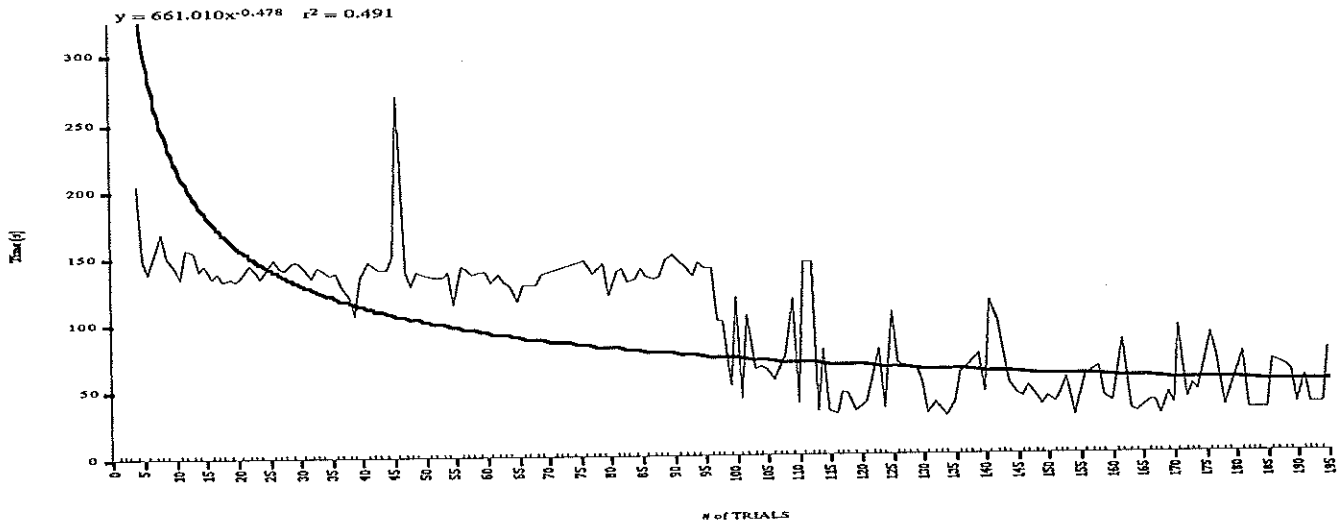
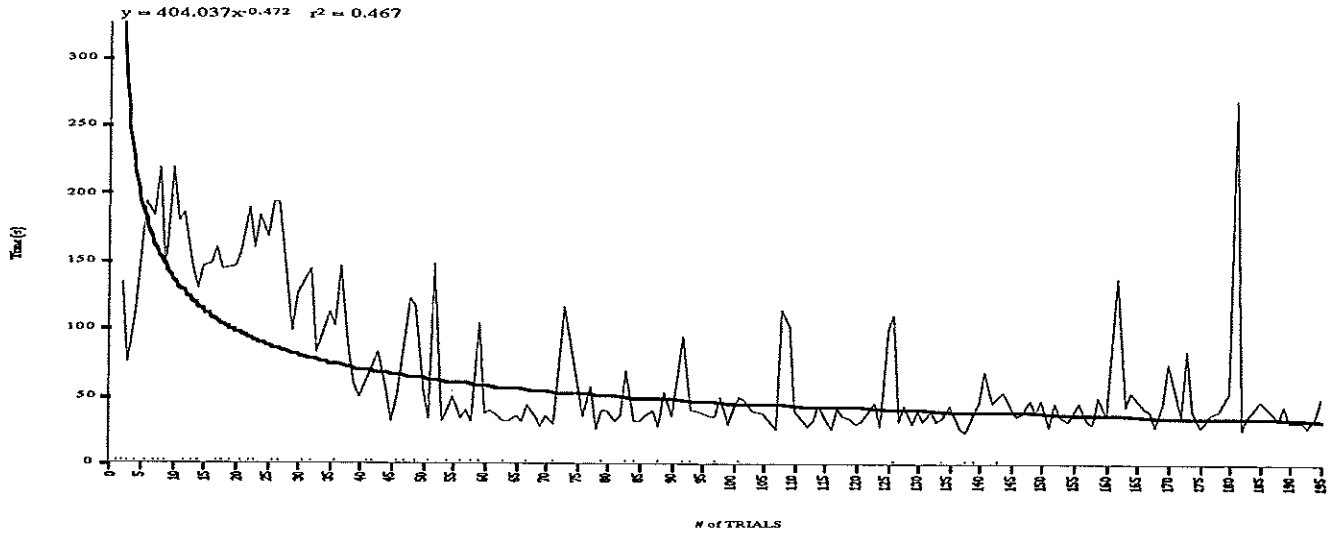


TL: SHUT DOWN



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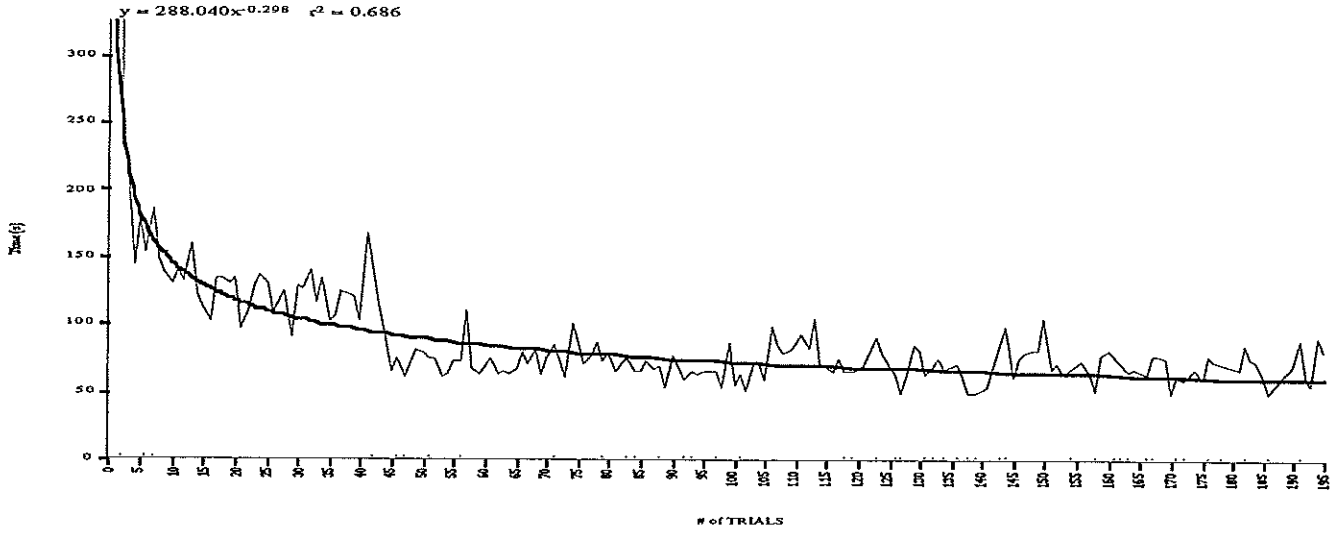

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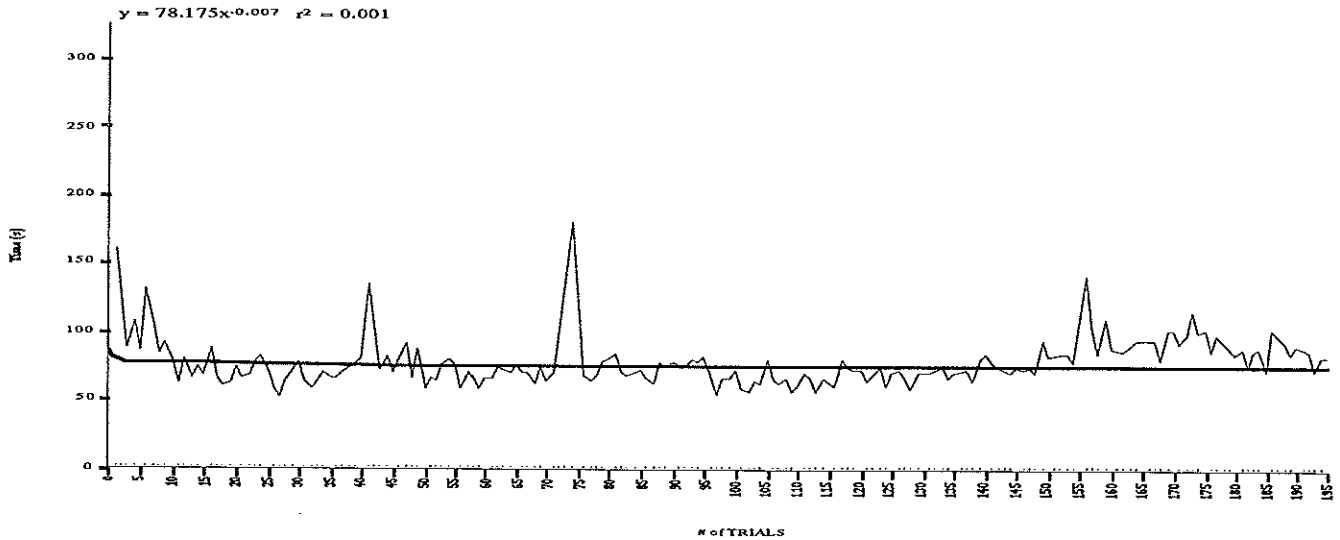
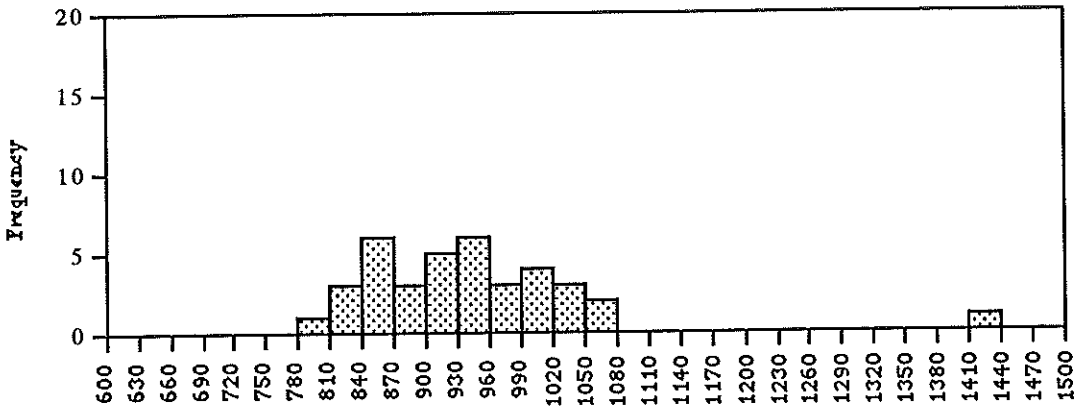
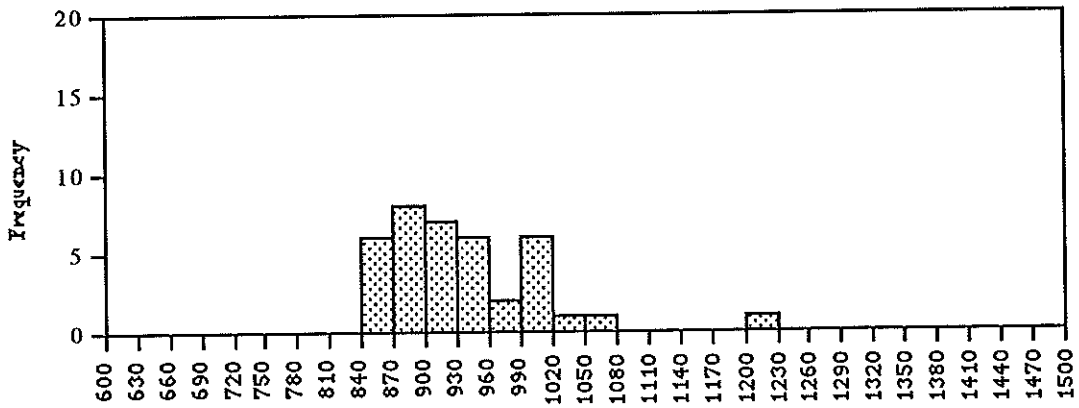


APPENDIX D1:

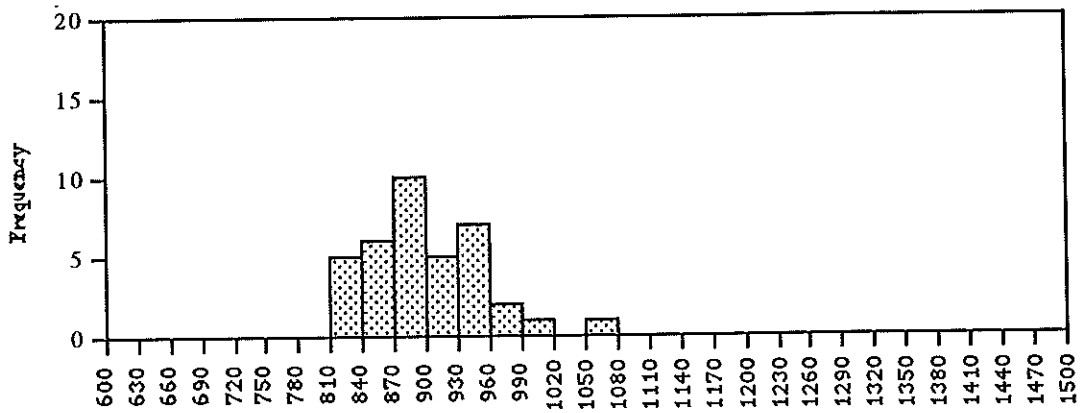
Frequency Distributions for Total Trial Times



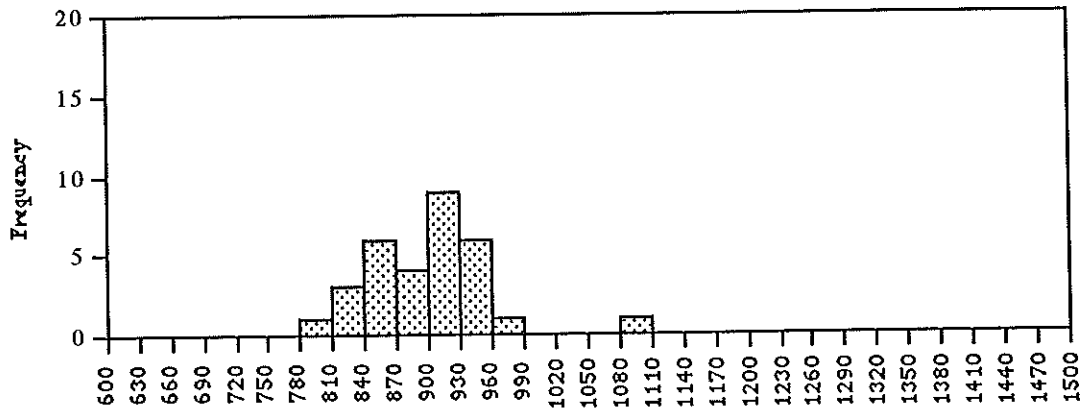
TOTAL TIMES DISTRIBUTION
TRIALS: AS 45-84



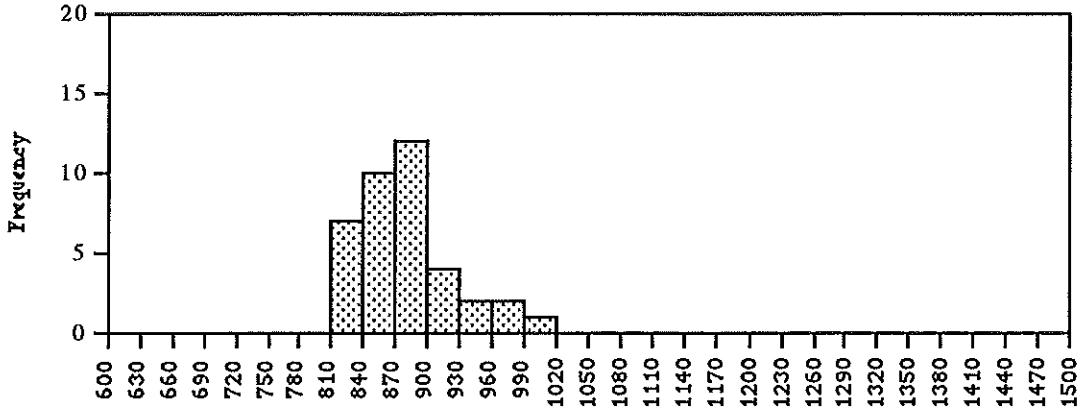
TOTAL TIMES DISTRIBUTION
TRIALS: AS 85-124



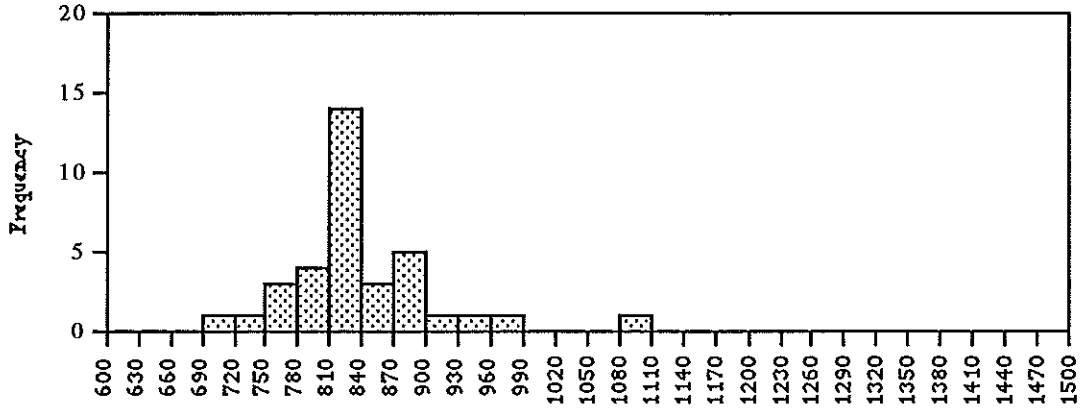
TOTAL TIMES DISTRIBUTION
TRIALS: AS 125-165



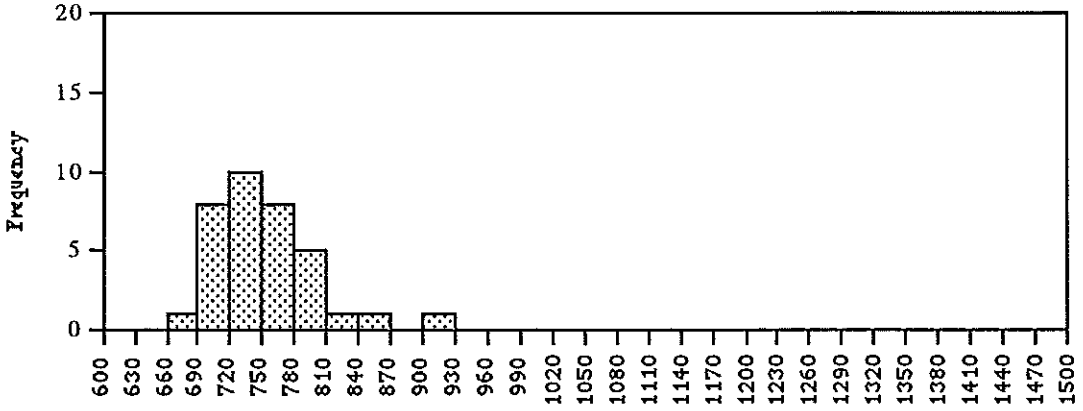
TOTAL TIMES DISTRIBUTION
TRIALS: AS 166-206



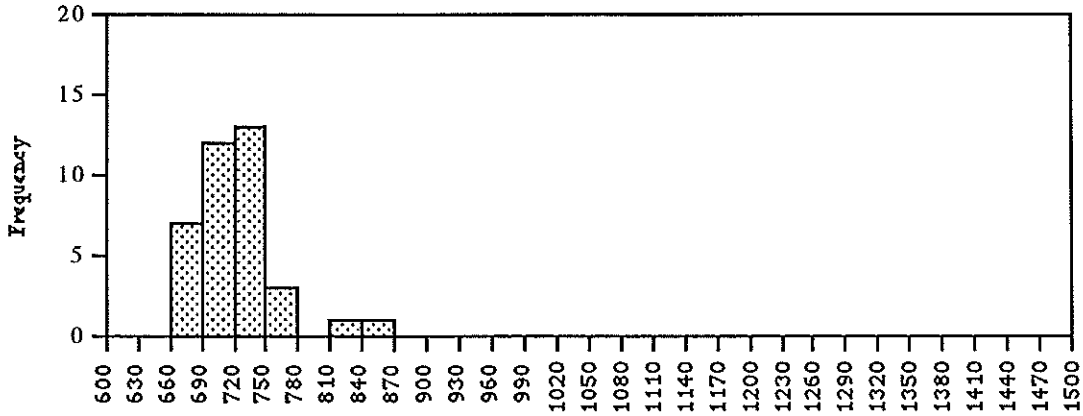
TOTAL TIMES DISTRIBUTION
TRIALS: AV 45-84



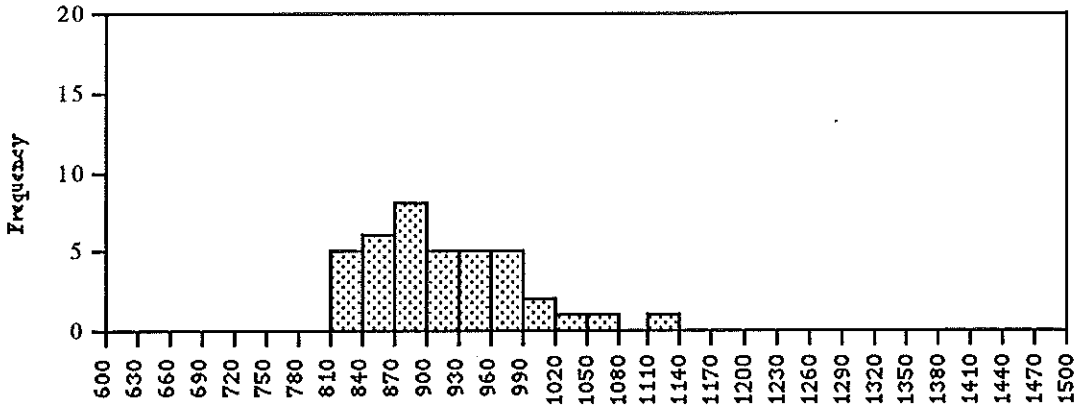
TOTAL TIMES DISTRIBUTION
TRIALS: AV 85-124



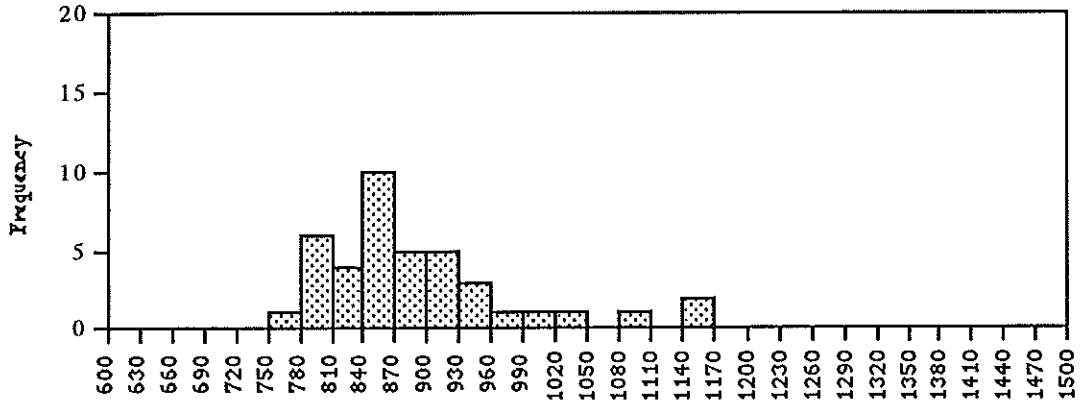
TOTAL TIMES DISTRIBUTION
TRIALS: AV 125-165



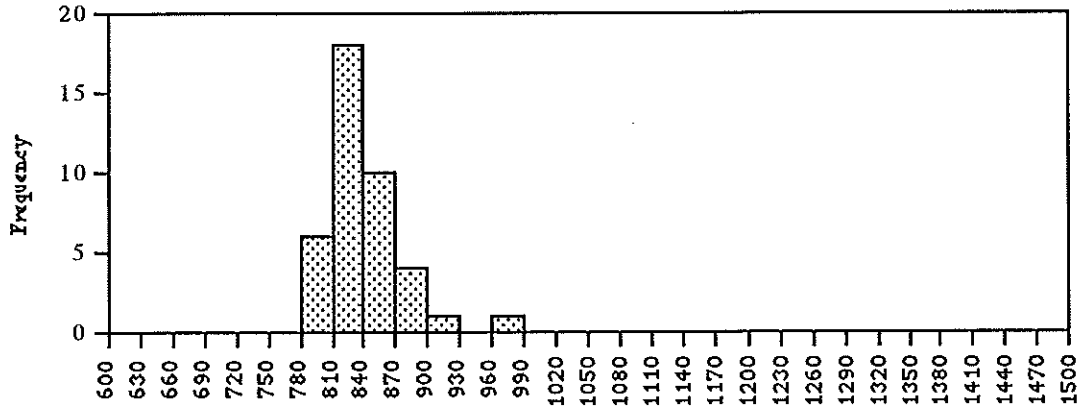
TOTAL TIMES DISTRIBUTION
TRIALS: AV 166-206



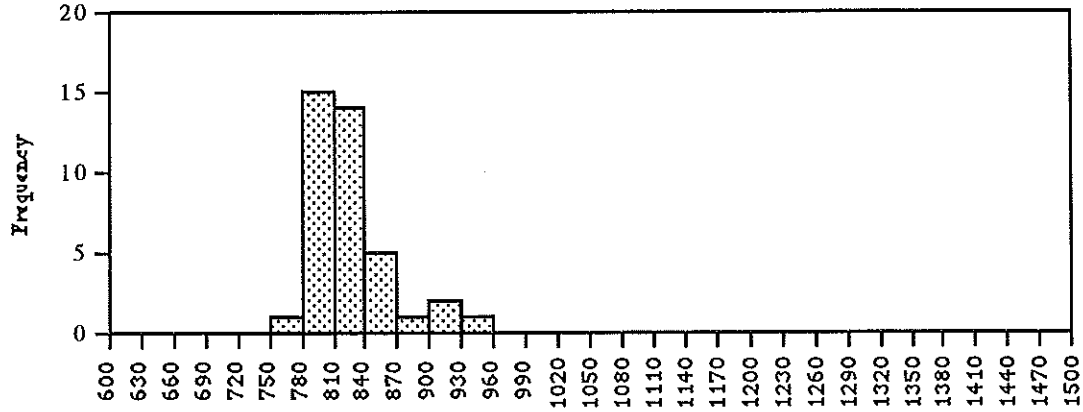
TOTAL TIMES DISTRIBUTION
TRIALS: IS 45-84



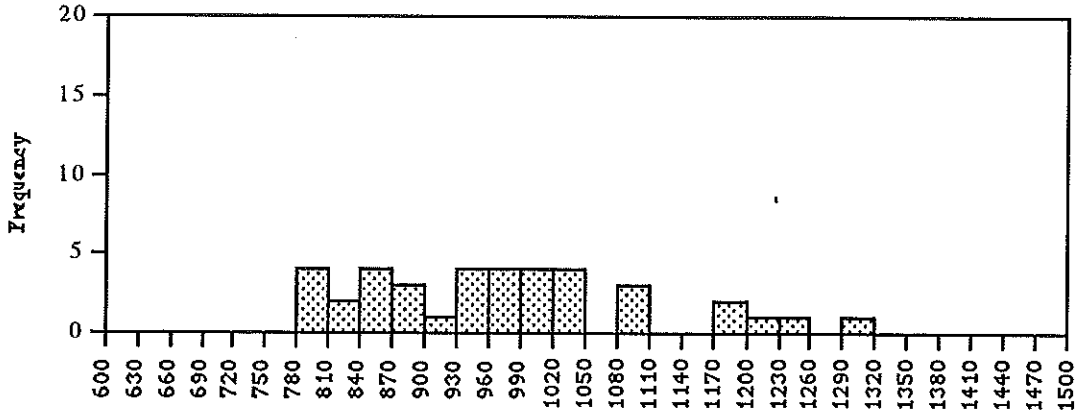
TOTAL TIMES DISTRIBUTION
TRIALS: IS 85-124



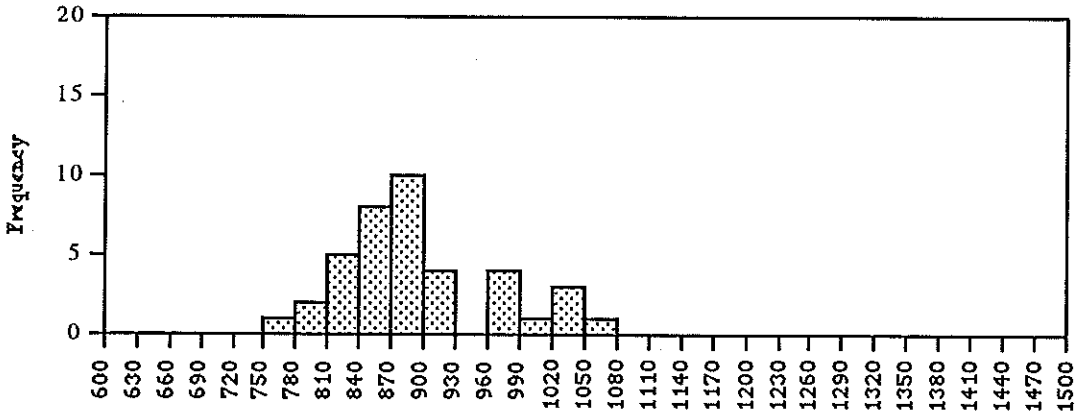
TOTAL TIMES DISTRIBUTION
TRIALS: IS 125-165



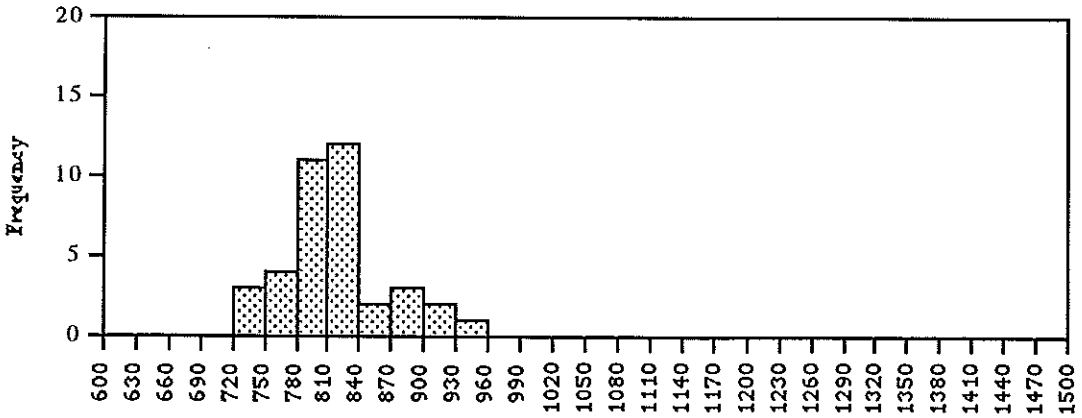
TOTAL TIMES DISTRIBUTION
TRIALS: IS 166-206



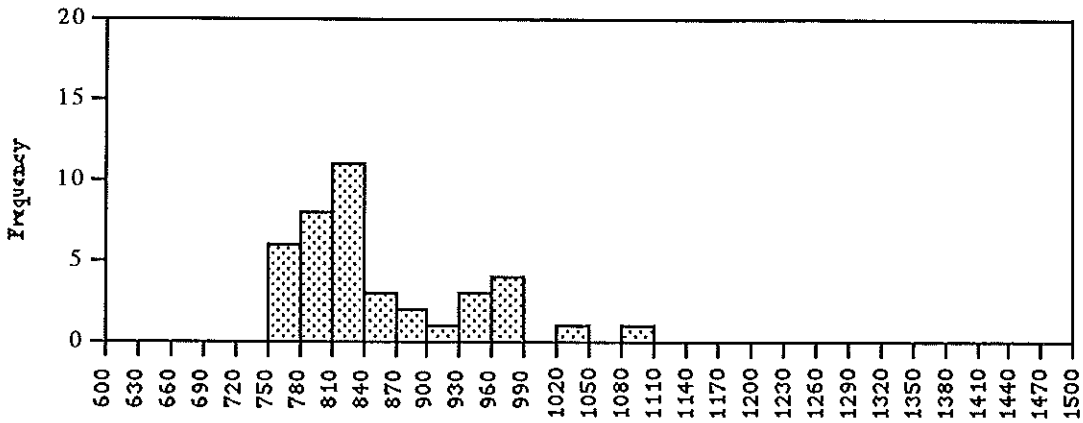
TOTAL TIMES DISTRIBUTION
TRIALS: ML 45-84



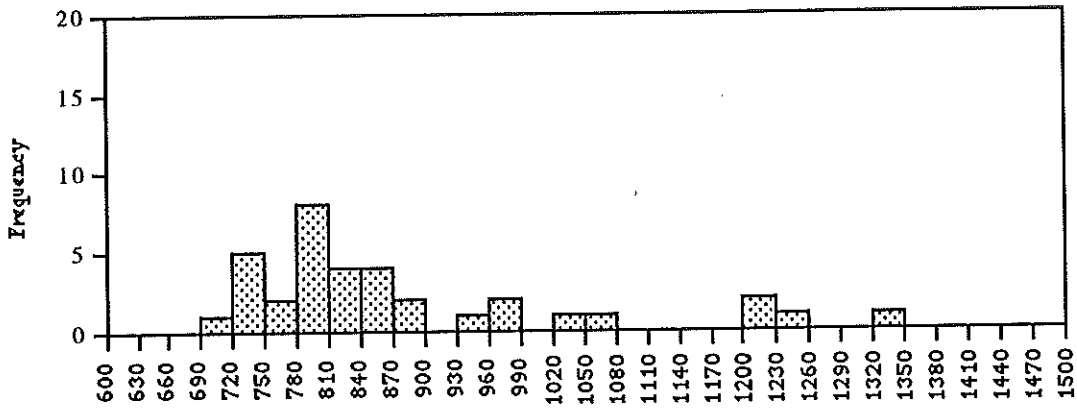
TOTAL TIMES DISTRIBUTION
TRIALS: ML 85-124



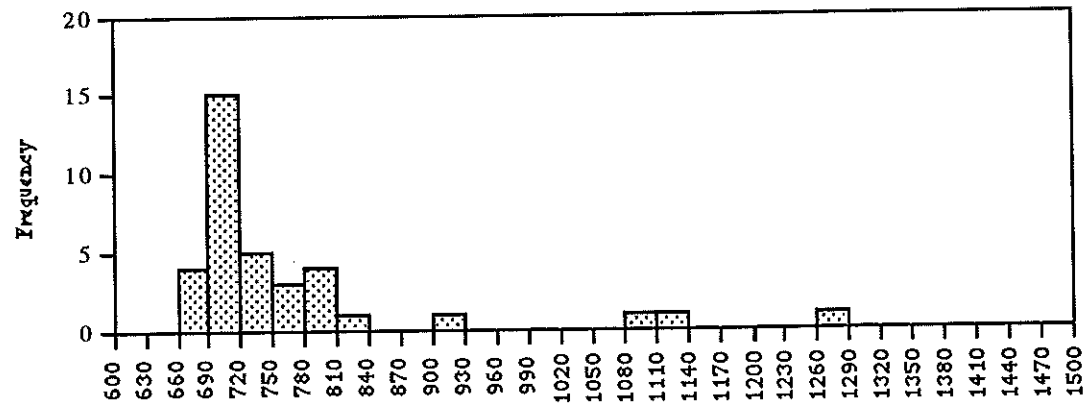
TOTAL TIMES DISTRIBUTION
TRIALS: ML 125-165



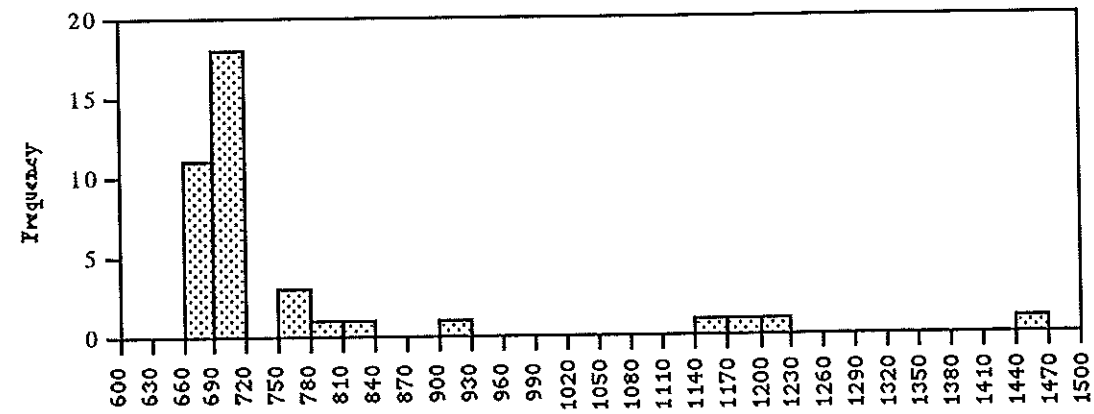
TOTAL TIMES DISTRIBUTION
TRIALS: ML 166-206



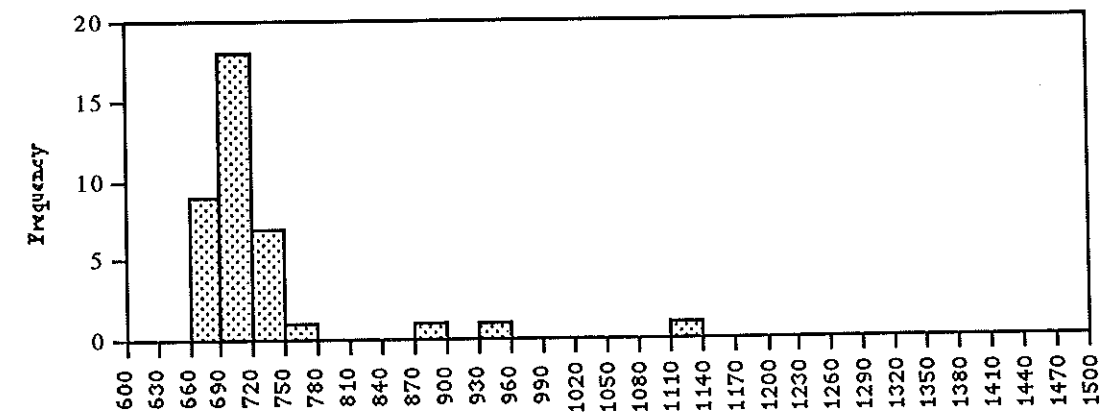
TOTAL TIMES DISTRIBUTION
TRIALS: TL 45-84



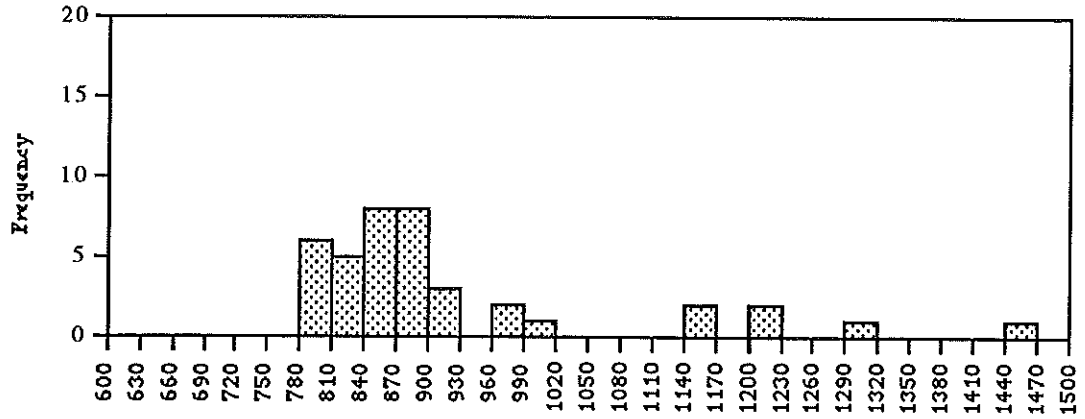
TOTAL TIMES DISTRIBUTION
TRIALS: TL 85-124



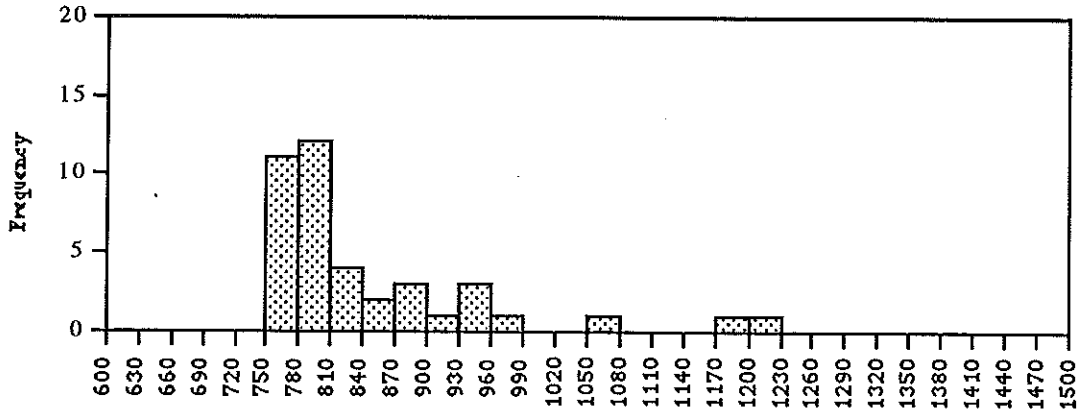
TOTAL TIMES DISTRIBUTION
TRIALS: TL 125-165



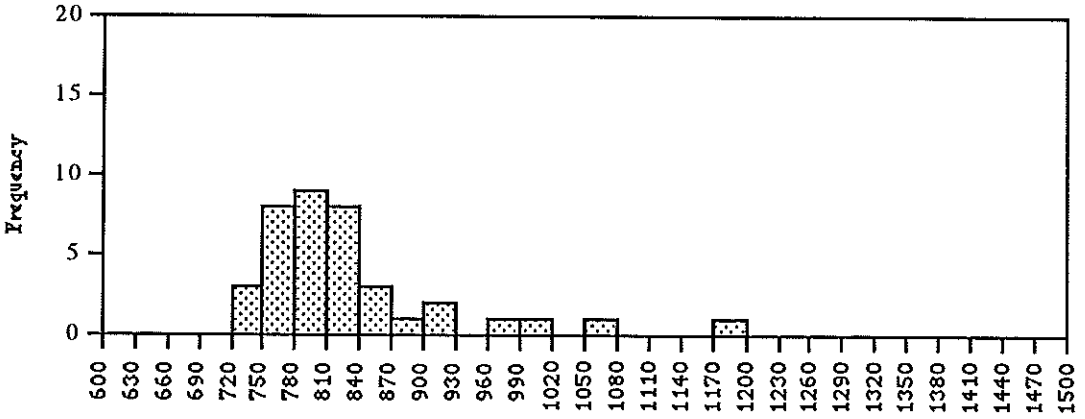
TOTAL TIMES DISTRIBUTION
TRIALS: TL 166-206



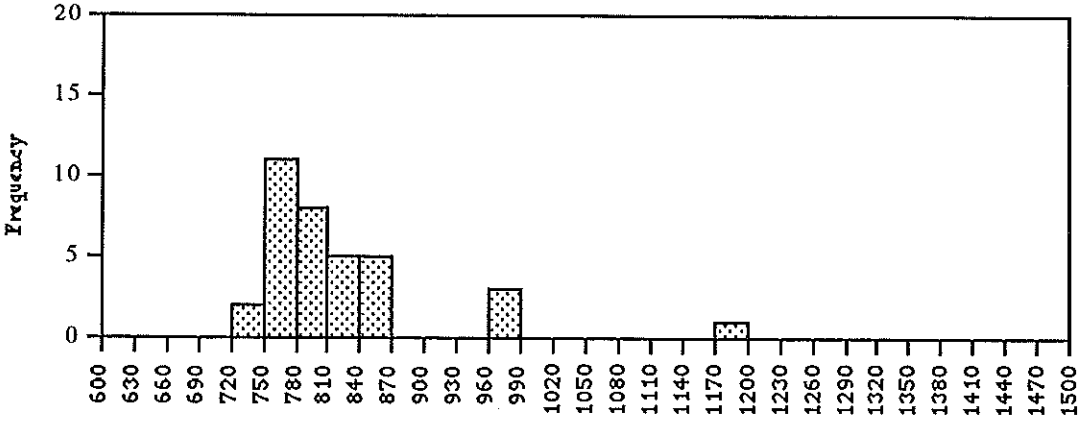
TOTAL TIMES DISTRIBUTION
TRIALS: WL 45-84



TOTAL TIMES DISTRIBUTION
TRIALS: WL 85-124



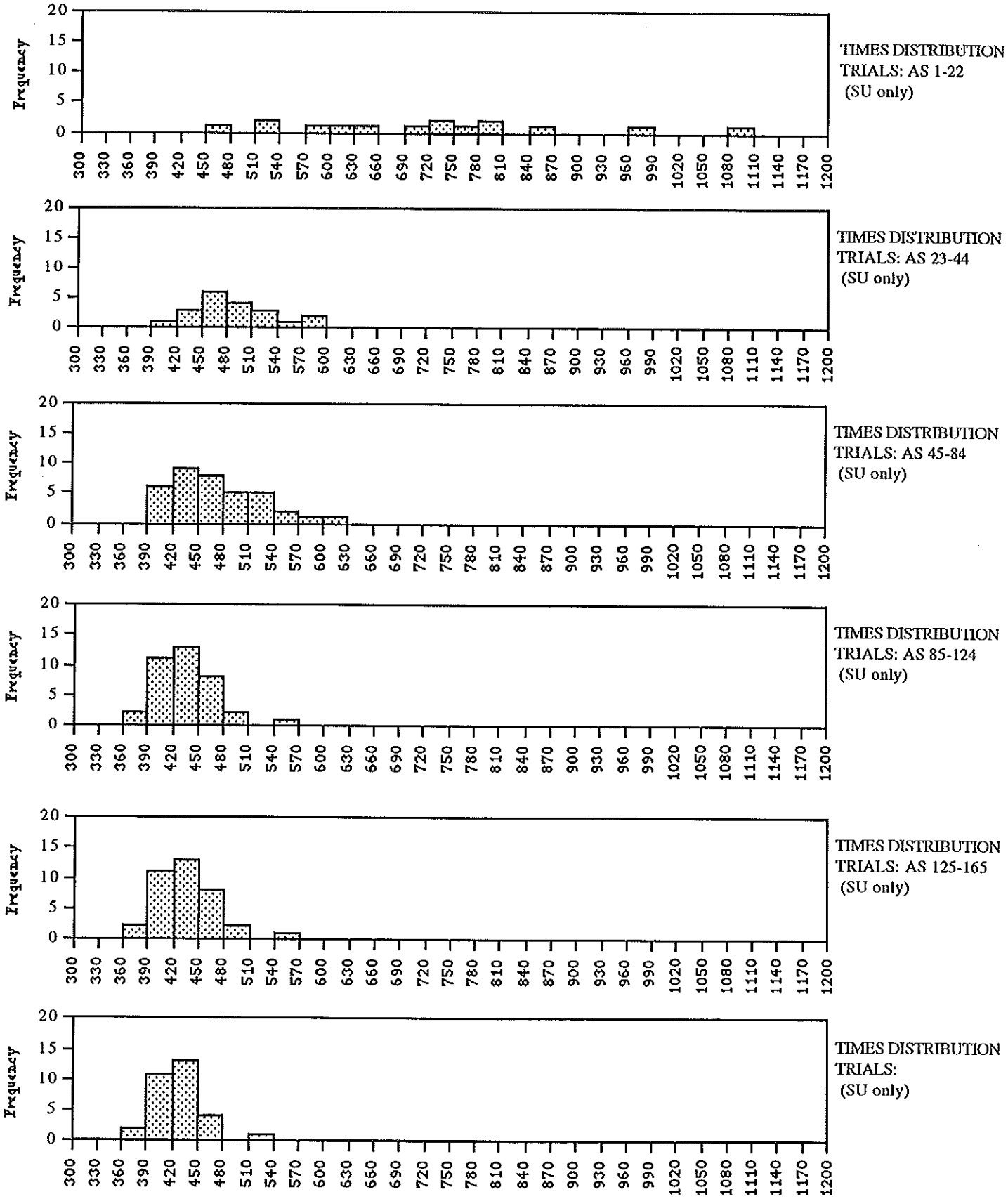
TOTAL TIMES DISTRIBUTION
TRIALS: WL 125-165

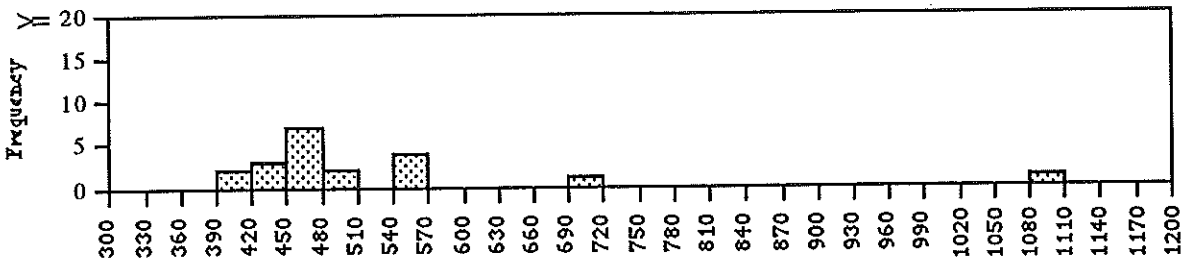


TOTAL TIMES DISTRIBUTION
TRIALS: WL 166-206

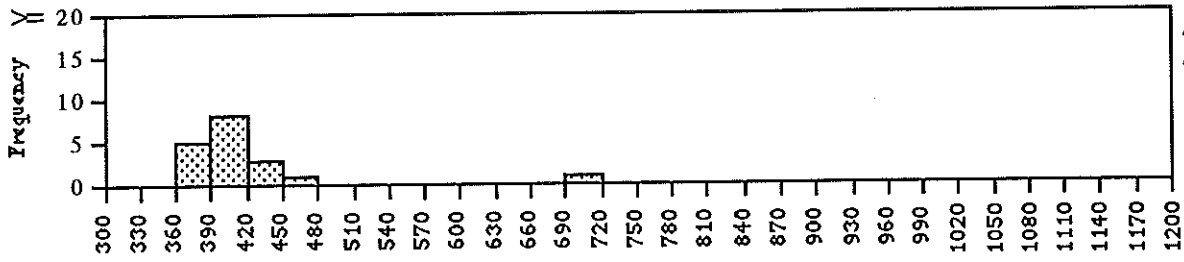
APPENDIX D2:

Frequency Distributions of Start-up Times

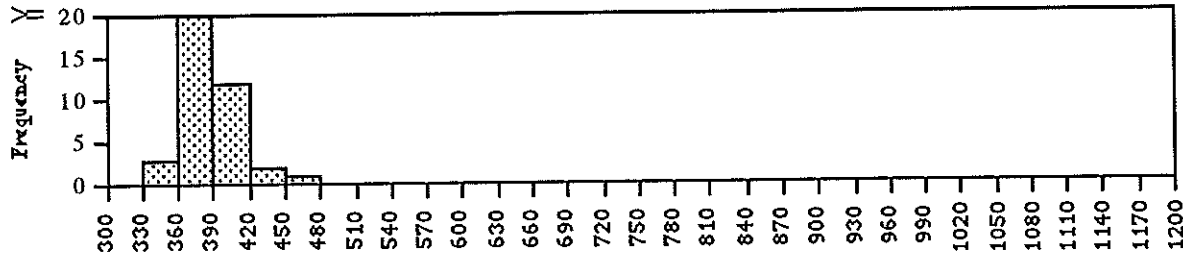

Frequency
20
15
10
5
0
300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900 930 960 990 1020 1050 1080 1110 1140 1170 1200
TIMES DISTRIBUTION
TRIALS: AS 1-22
(SU only)
TIMES DISTRIBUTION
TRIALS: AS 23-44
(SU only)
TIMES DISTRIBUTION
TRIALS: AS 45-84
(SU only)
TIMES DISTRIBUTION
TRIALS: AS 85-124
(SU only)
TIMES DISTRIBUTION
TRIALS: AS 125-165
(SU only)
TIMES DISTRIBUTION
TRIALS:
(SU only)



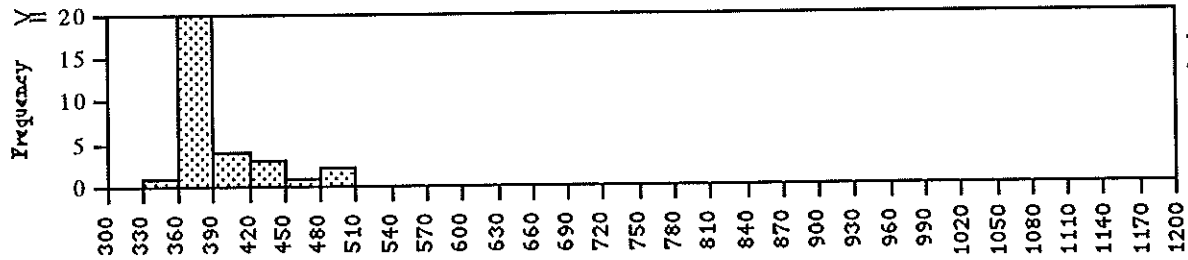
TIMES DISTRIBUTION
TRIALS: AV 1-22
(SU only)



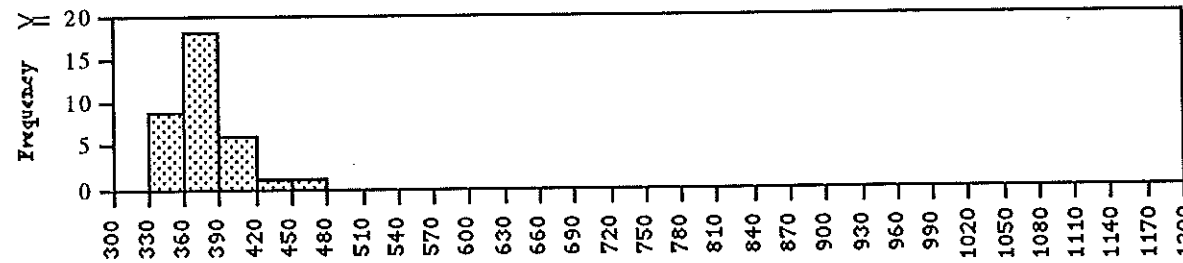
TIMES DISTRIBUTION
TRIALS: AV 23-44
(SU only)



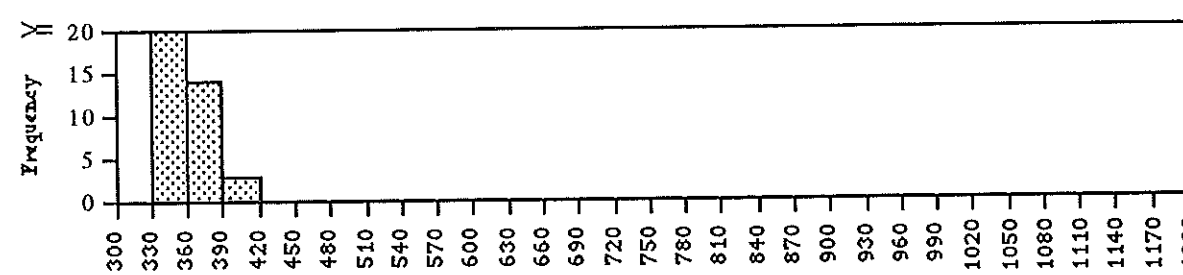
TIMES DISTRIBUTION
TRIALS: AV 45-84
(SU only)



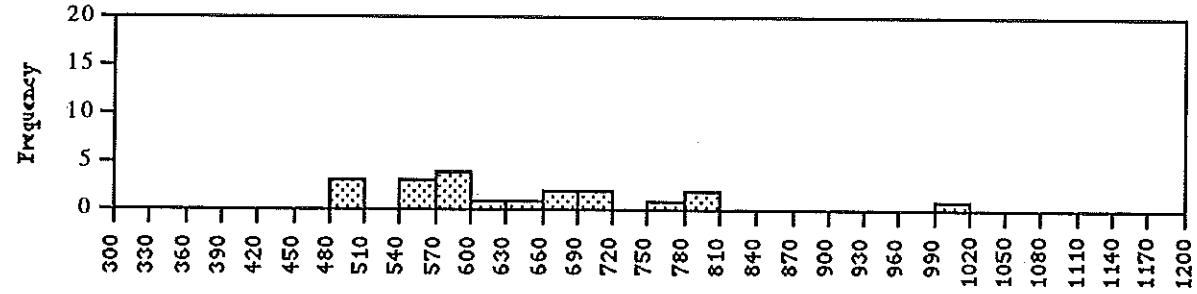
TIMES DISTRIBUTION
TRIALS: AV 85-124
(SU only)



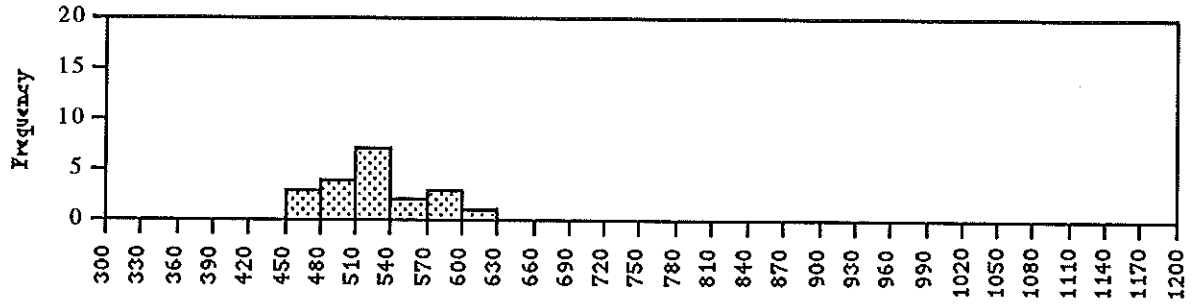
TIMES DISTRIBUTION
TRIALS: AV 125-165
(SU only)



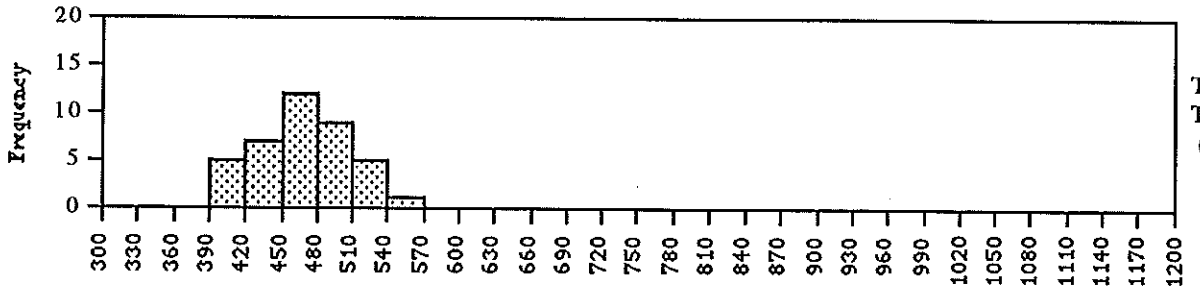
TIMES DISTRIBUTION
TRIALS: AV 166-206
(SU only)



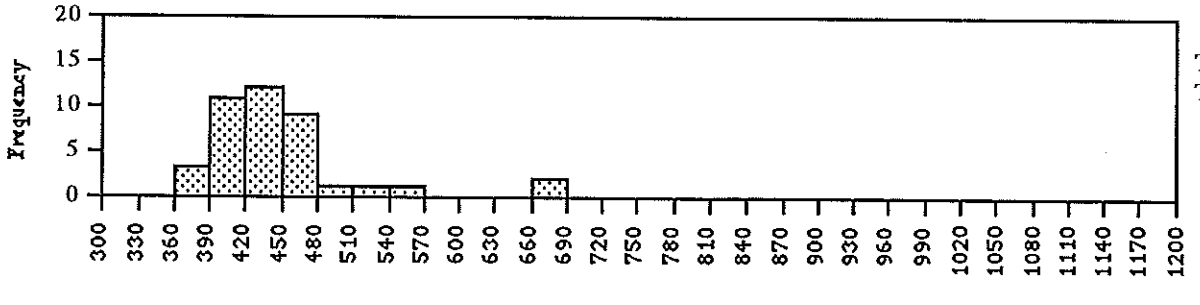
TIMES DISTRIBUTION
TRIALS: IS 1-22
(SU only)



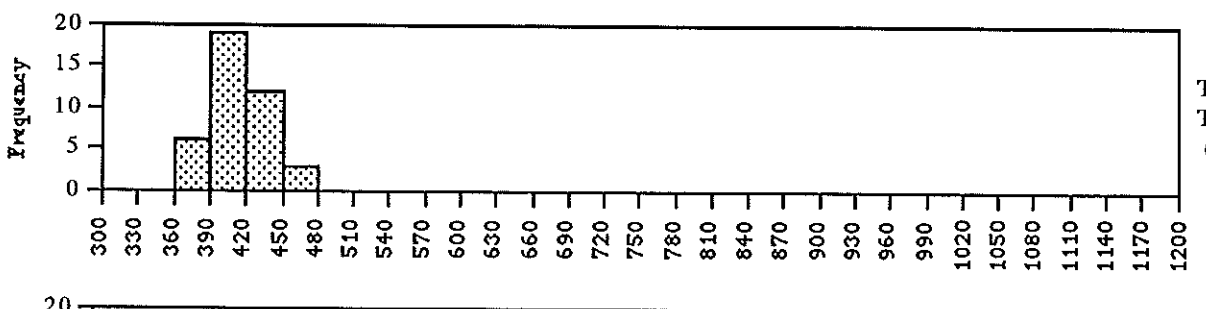
TIMES DISTRIBUTION
TRIALS: IS 23-44
(SU only)



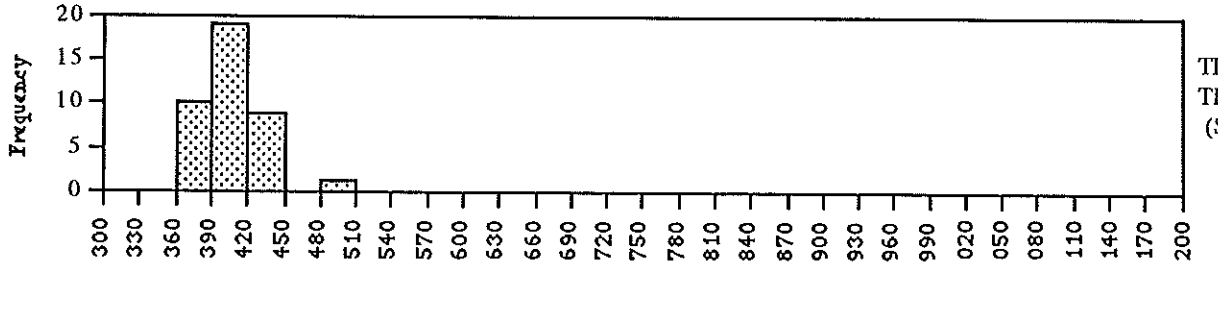
TIMES DISTRIBUTION
TRIALS: IS 45-84
(SU only)



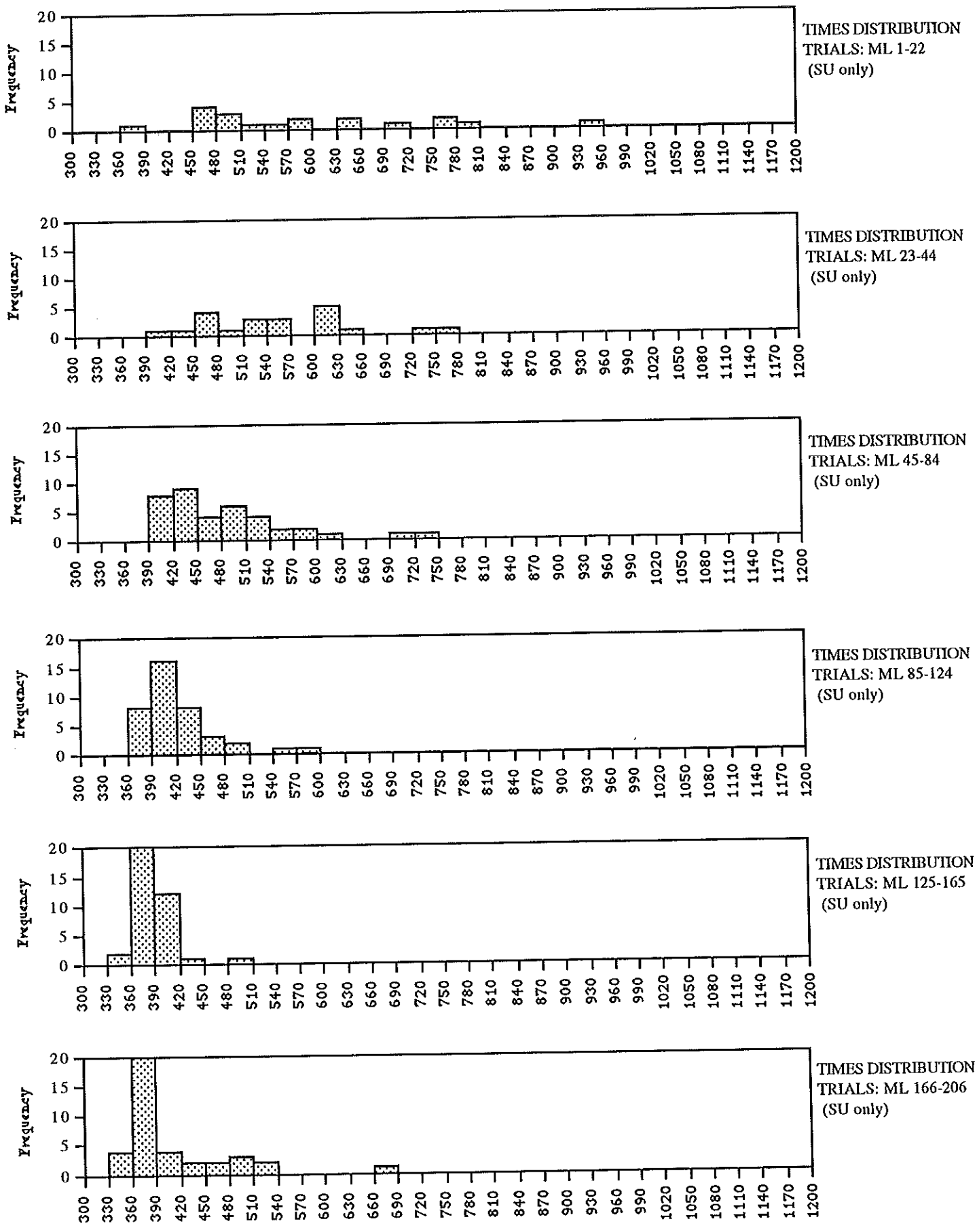
TIMES DISTRIBUTION
TRIALS: IS 85-124
(SU only)

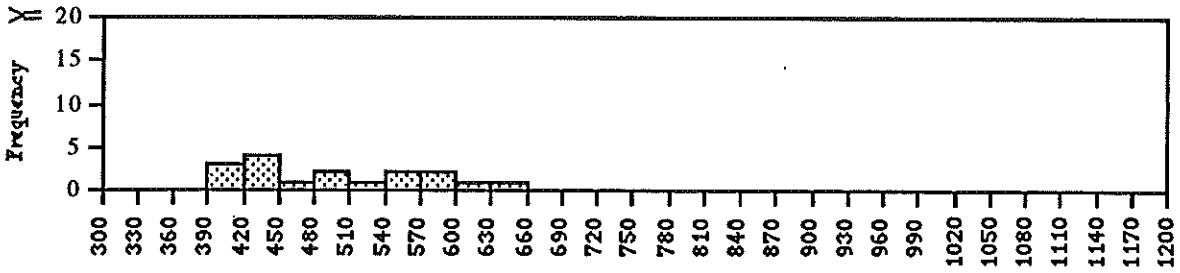


TIMES DISTRIBUTION
TRIALS: IS 125-165
(SU only)

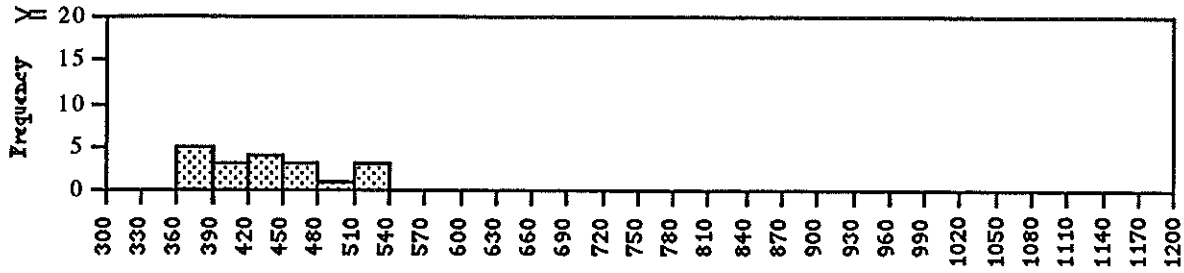


TIMES DISTRIBUTION
TRIALS: IS 166-206
(SU only)

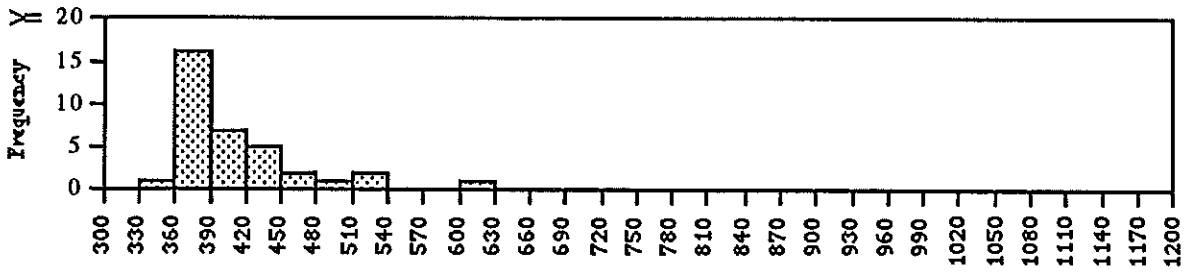

Frequency
20
15
10
5
0
300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900 930 960 990 1020 1050 1080 1110 1140 1170 1200
TIMES DISTRIBUTION
TRIALS: ML 1-22
(SU only)
TIMES DISTRIBUTION
TRIALS: ML 23-44
(SU only)
TIMES DISTRIBUTION
TRIALS: ML 45-84
(SU only)
TIMES DISTRIBUTION
TRIALS: ML 85-124
(SU only)
TIMES DISTRIBUTION
TRIALS: ML 125-165
(SU only)
TIMES DISTRIBUTION
TRIALS: ML 166-206
(SU only)



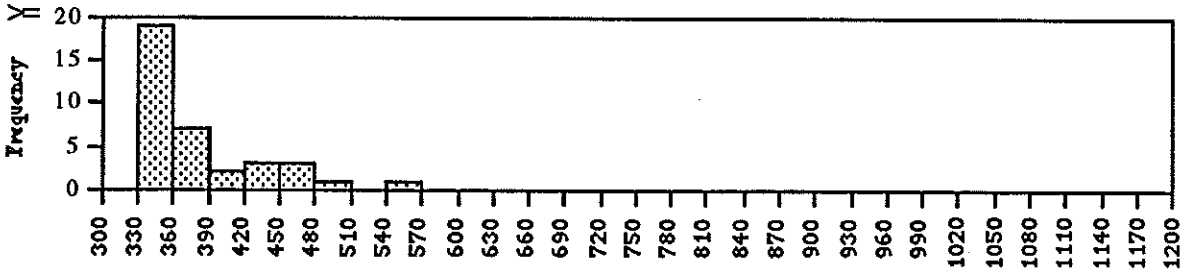
TIMES DISTRIBUTION
TRIALS: TL 1-22
(SU only)



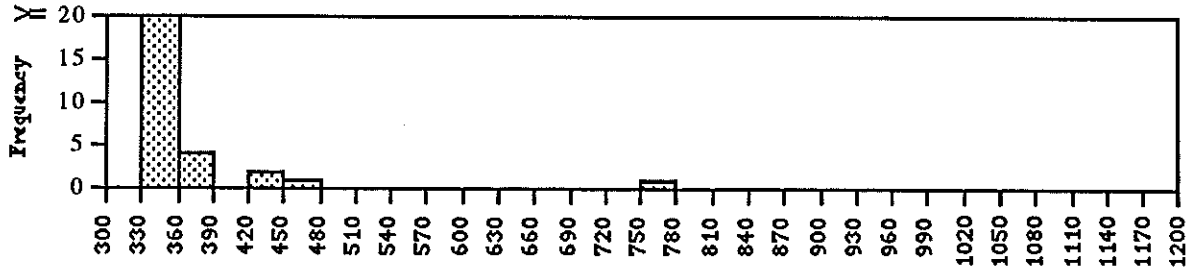
TIMES DISTRIBUTION
TRIALS: TL 23-44
(SU only)



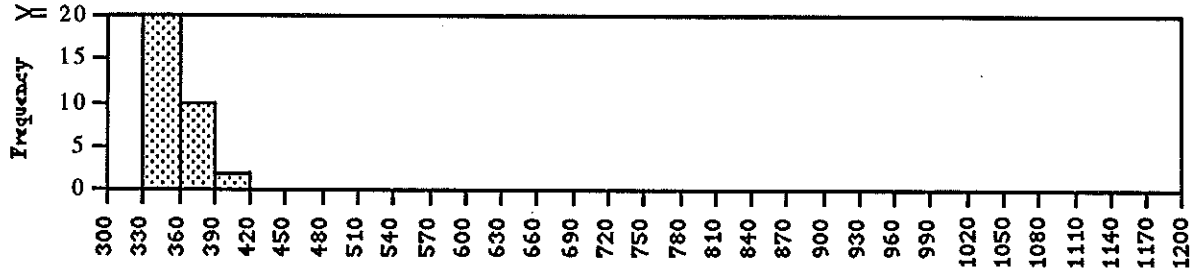
TIMES DISTRIBUTION
TRIALS: TL 45-84
(SU only)



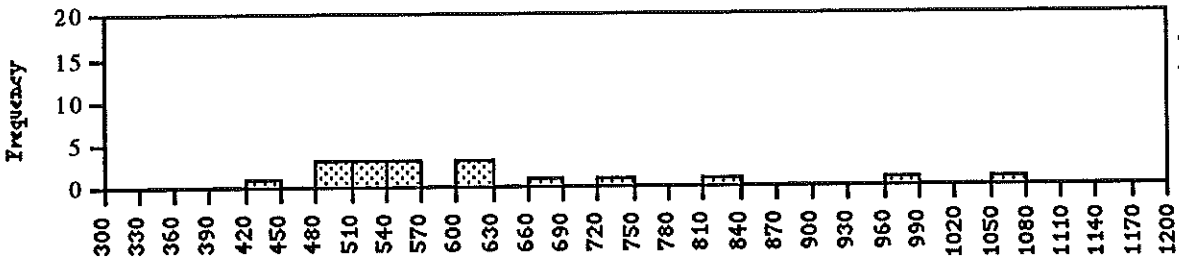
TIMES DISTRIBUTION
TRIALS: TL 85-124
(SU only)



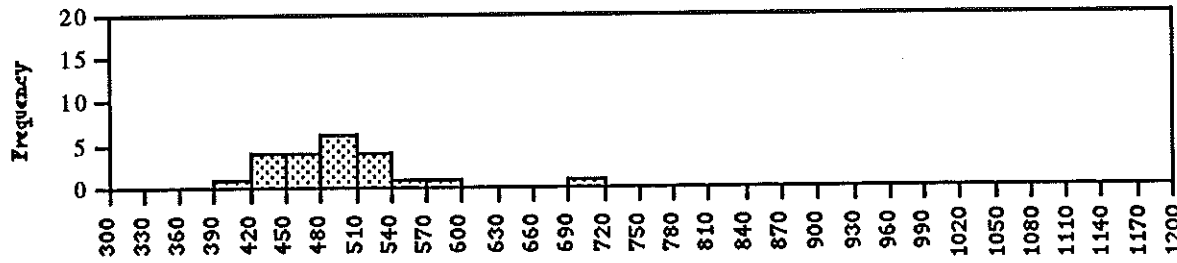
TIMES DISTRIBUTION
TRIALS: TL 125-165
(SU only)



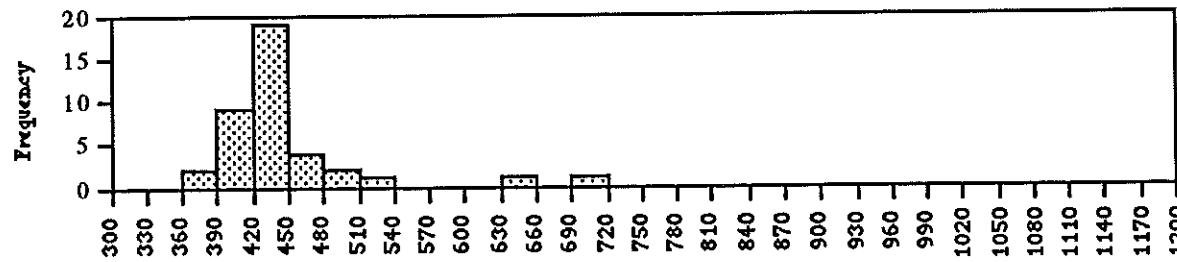
TIMES DISTRIBUTION
TRIALS: TL 166-206
(SU only)



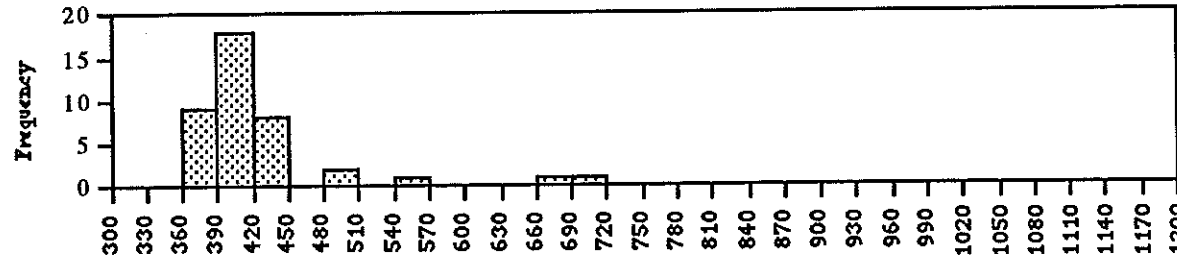
TIMES DISTRIBUTION
TRIALS: WL 1-22
(SU only)



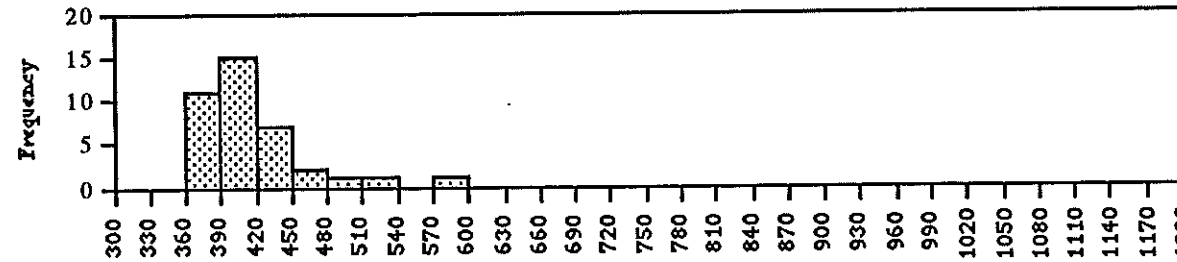
TIMES DISTRIBUTION
TRIALS: WL 23-44
(SU only)



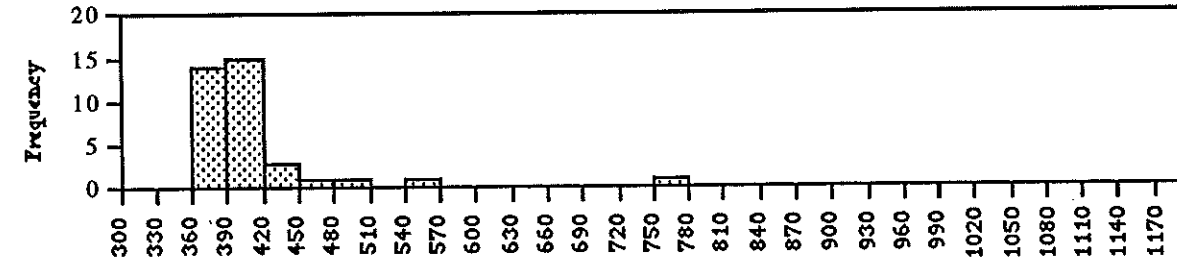
TIMES DISTRIBUTION
TRIALS: WL 45-84
(SU only)



TIMES DISTRIBUTION
TRIALS: WL 85-124
(SU only)



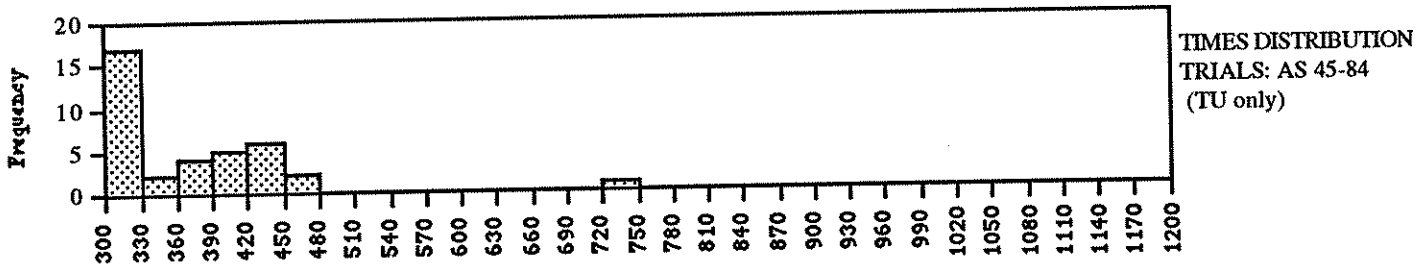
TIMES DISTRIBUTION
TRIALS: WL 125-165
(SU only)



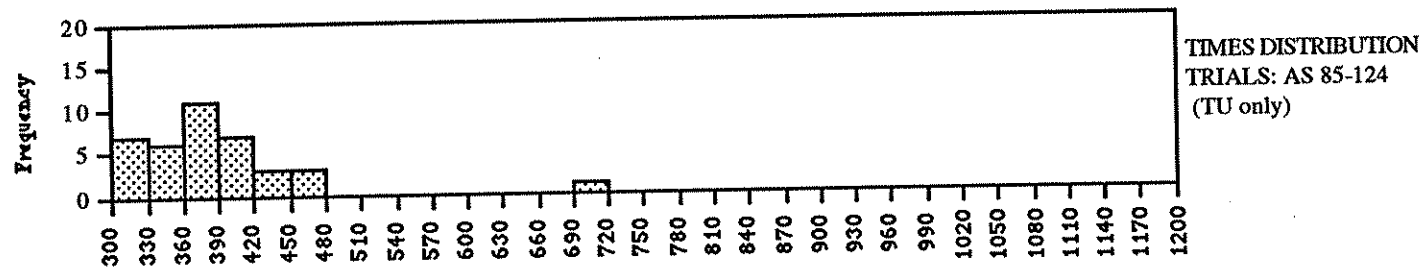
TIMES DISTRIBUTION
TRIALS: WL 166-206
(SU only)

APPENDIX D3:

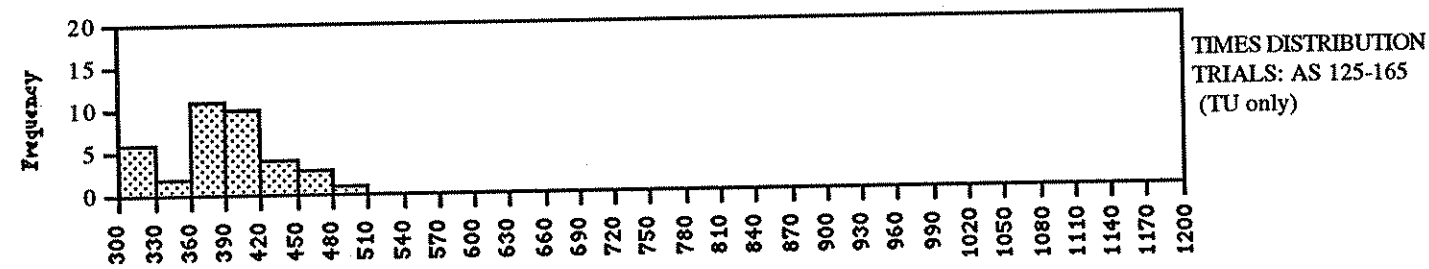
Frequency Distributions of Tuning Times



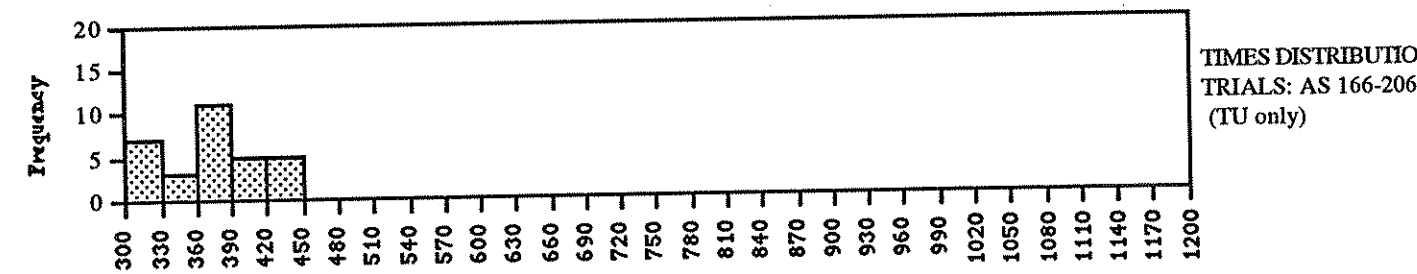
TIMES DISTRIBUTION
TRIALS: AS 45-84
(TU only)



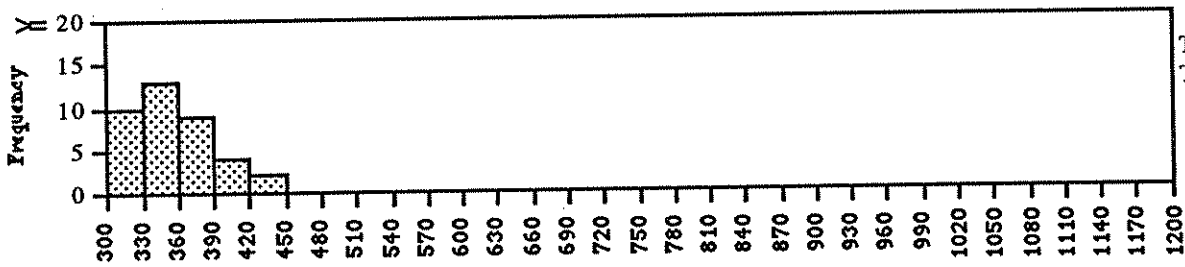
TIMES DISTRIBUTION
TRIALS: AS 85-124
(TU only)



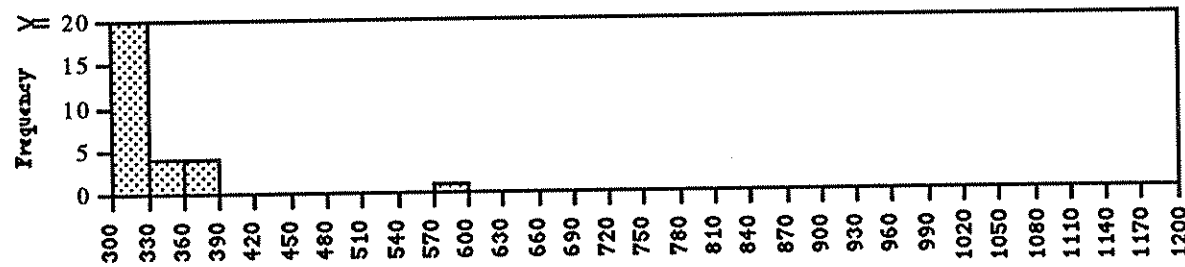
TIMES DISTRIBUTION
TRIALS: AS 125-165
(TU only)



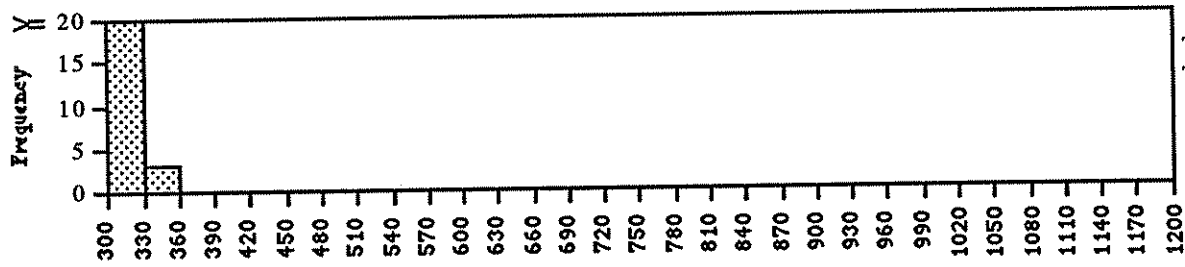
TIMES DISTRIBUTION
TRIALS: AS 166-206
(TU only)



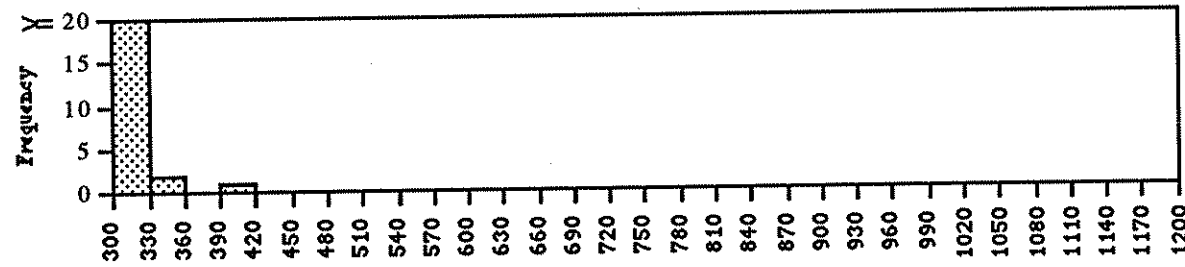
TIMES DISTRIBUTION
TRIALS: AV 45-84
(TU only)



TIMES DISTRIBUTION
TRIALS: AV 85-124
(TU only)



TIMES DISTRIBUTION
TRIALS: AV 125-165
(TU only)



TIMES DISTRIBUTION
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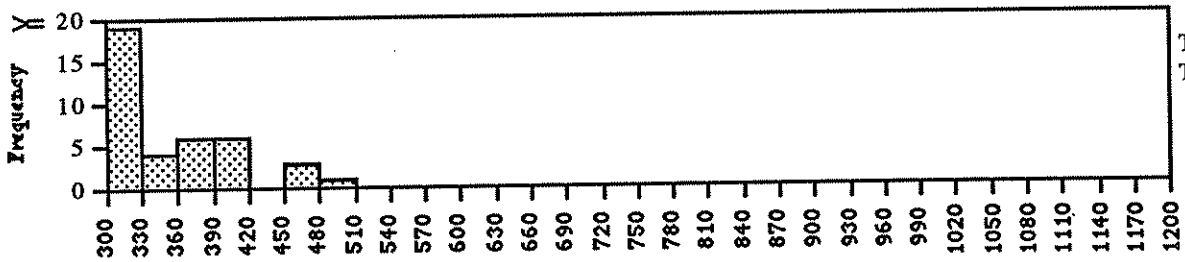
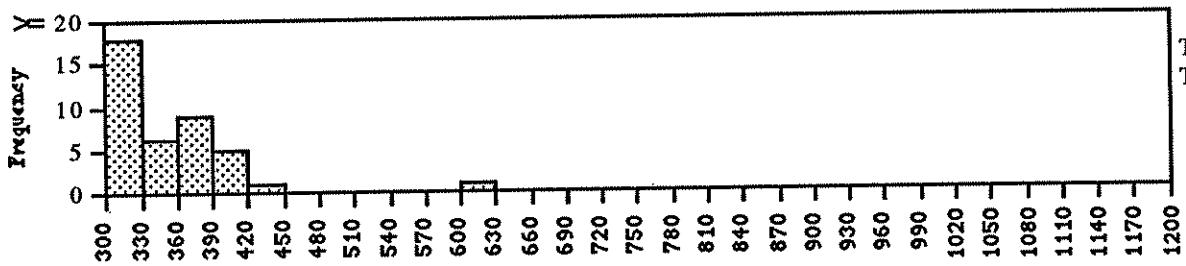
(TU only)



TIMES DISTRIBUTION
TRIALS: IS 45-84
(TU only)



TIMES DISTRIBUTION
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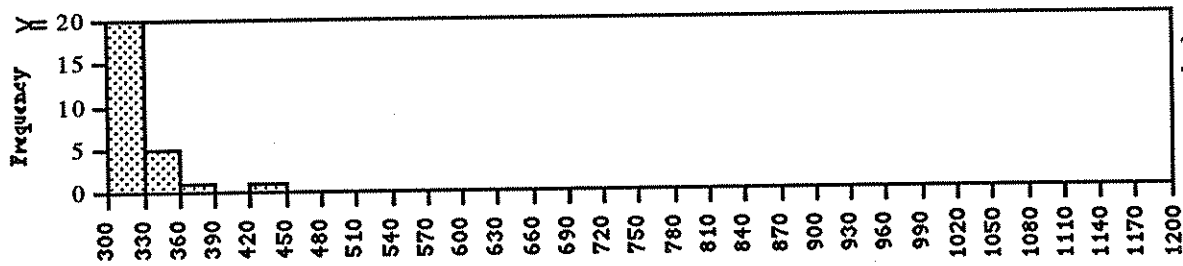
(TU only)



TIMES DISTRIBUTION
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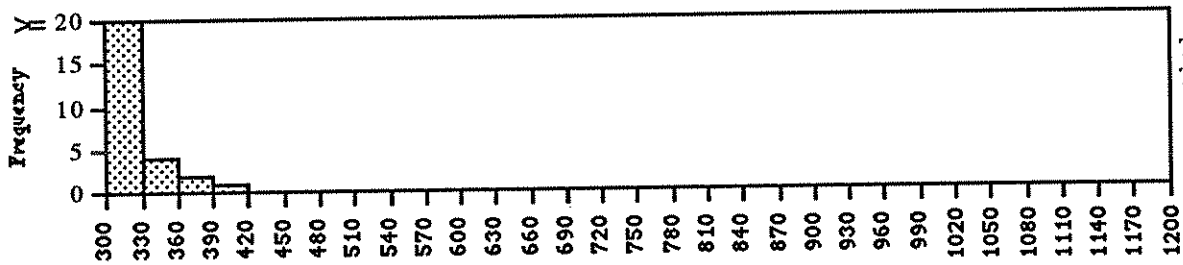
(TU only)



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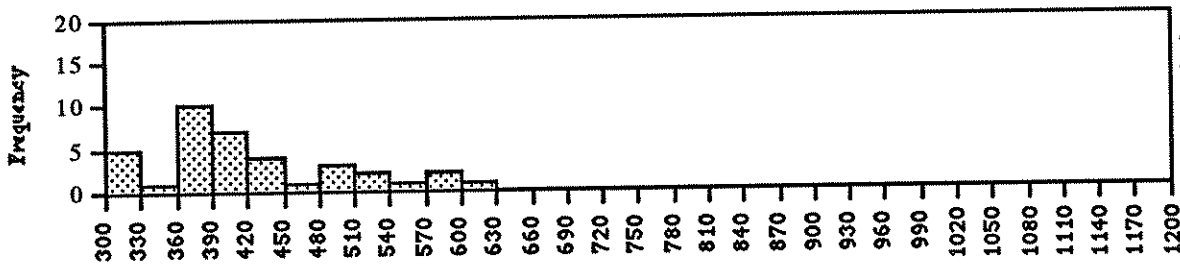
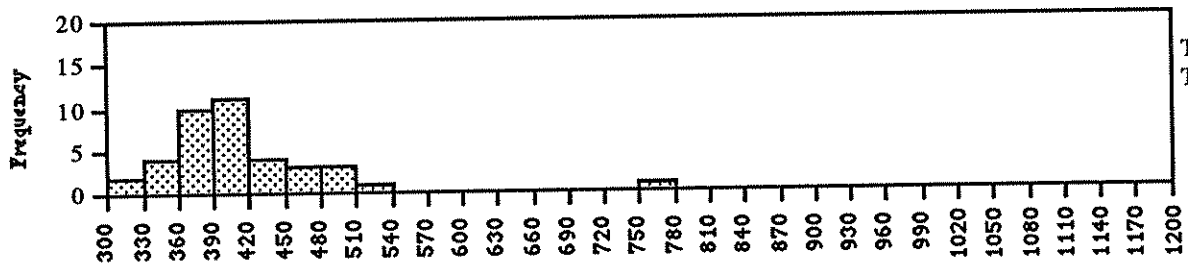
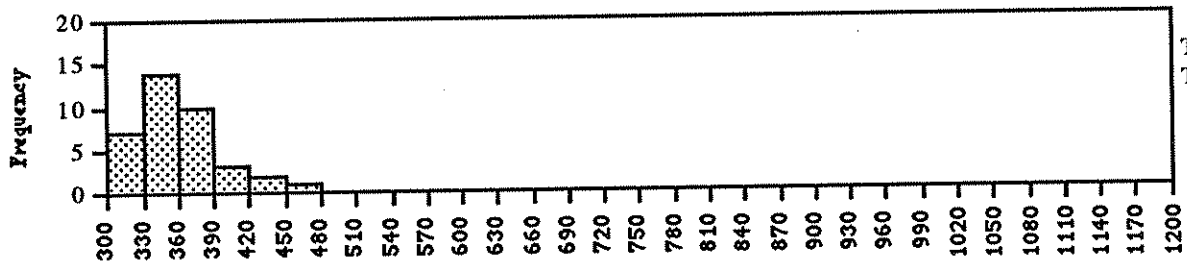
(TU only)



TIMES DISTRIBUTION
TRIALS: ML 45-84
(TU only)



TIMES DISTRIBUTION
TRIALS: ML 85-124
(TU only)



TIMES DISTRIBUTION
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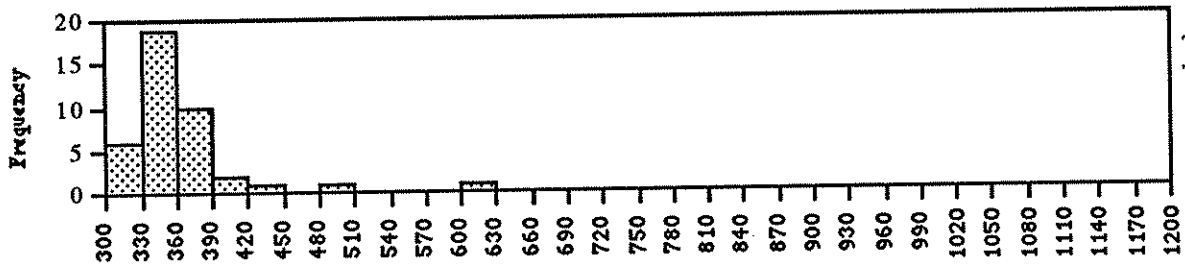
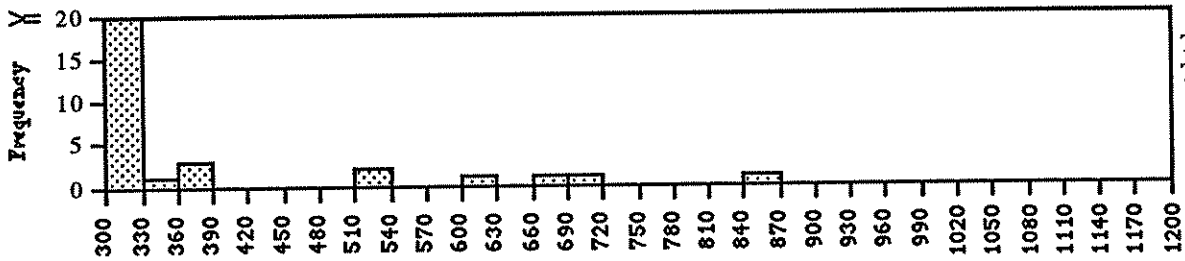
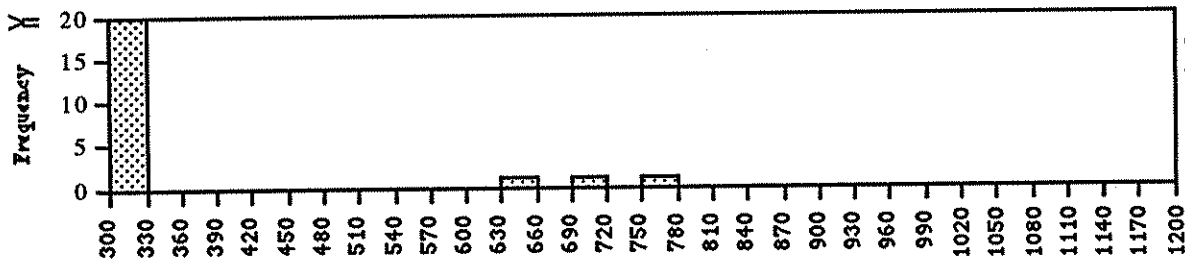
(TU only)



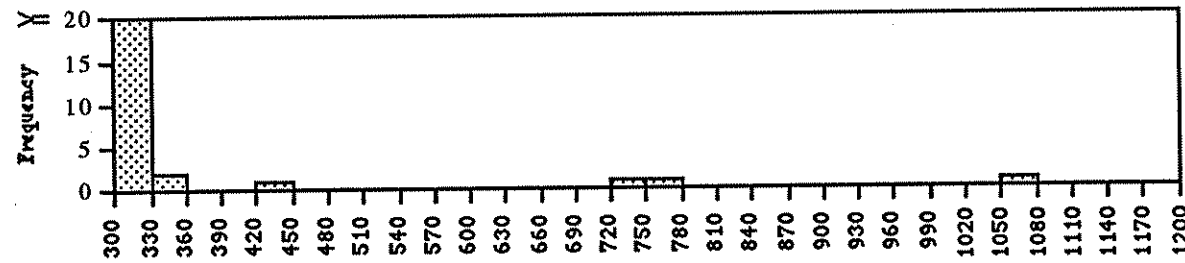
TIMES DISTRIBUTION
TRIALS: ML 166-206
(TU only)



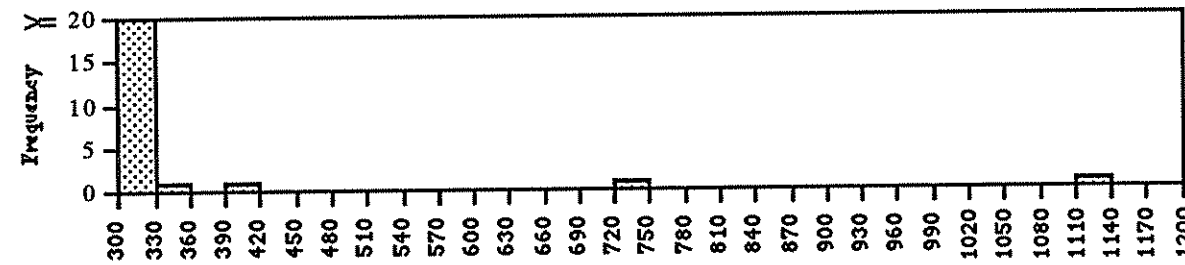
TIMES DISTRIBUTION
TRIALS: TL 45-84
(TU only)



TIMES DISTRIBUTION
TRIALS: TL 85-124
(TU only)



TIMES DISTRIBUTION
TRIALS: TL 125-165
(TU only)



TIMES DISTRIBUTION
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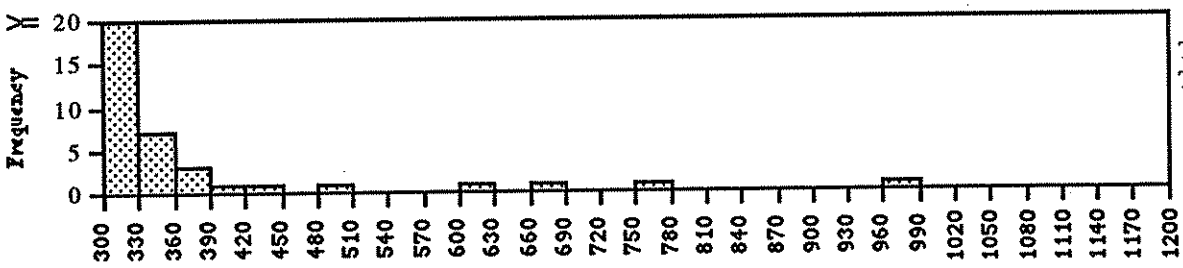
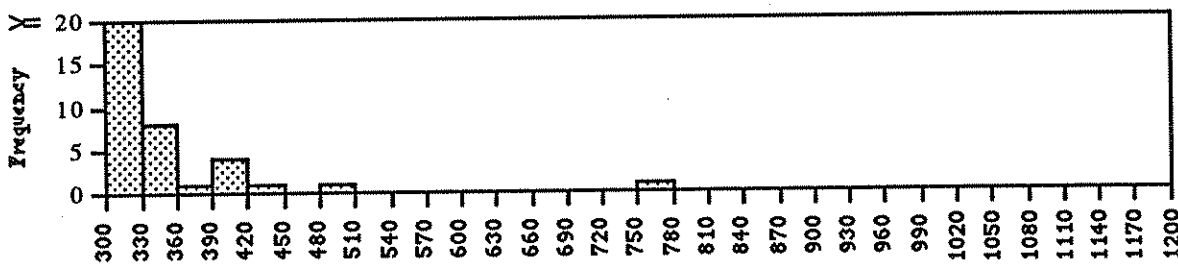
(TU only)



TIMES DISTRIBUTION
TRIALS: WL 45-84
(TU only)



TIMES DISTRIBUTION
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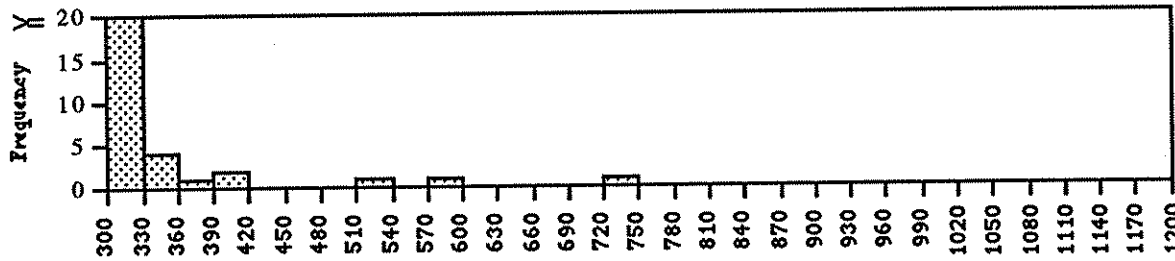
(TU only)



TIMES DISTRIBUTION
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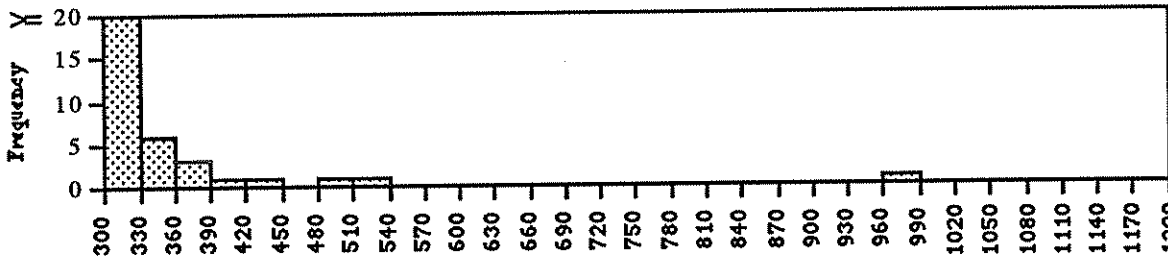
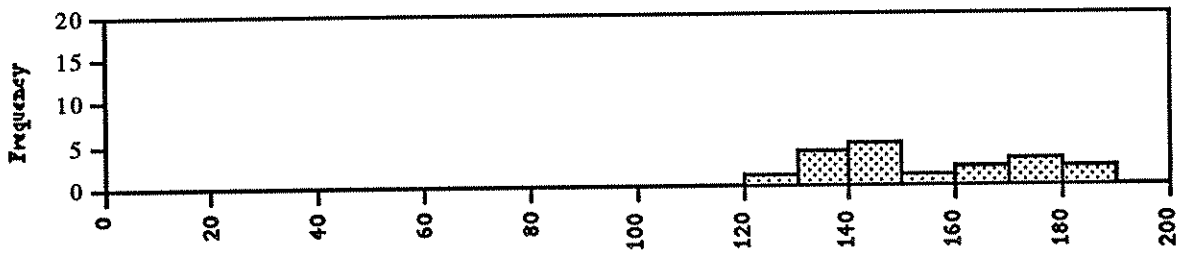
(TU only)



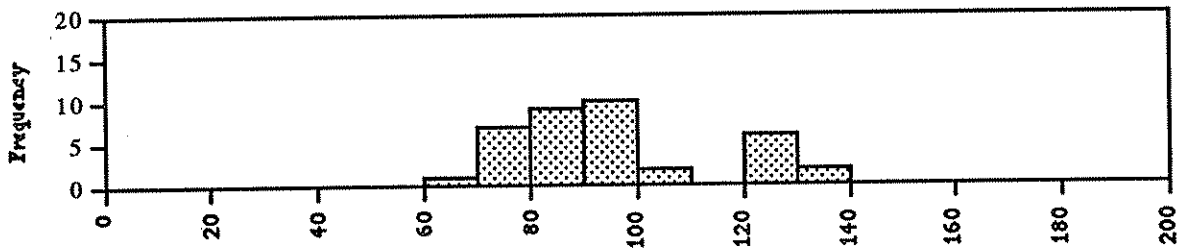
TIMES DISTRIBUTION
TRIALS: WL 166-206
(TU only)

APPENDIX D4:

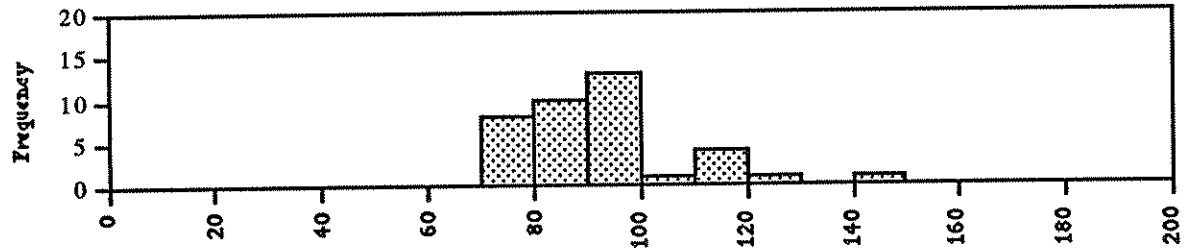
Frequency Distributions of Shut-Down Times



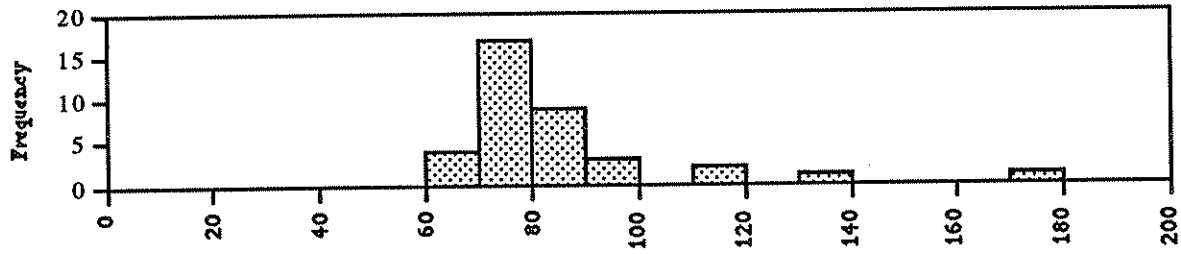
TIMES DISTRIBUTION
TRIALS: AS 23-44
(SD only)



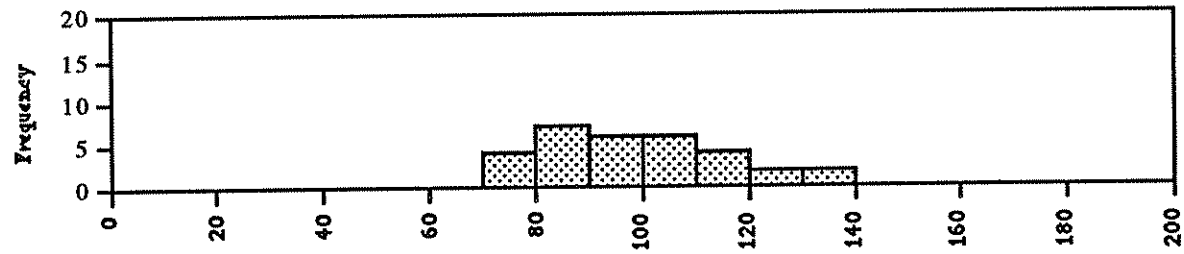
TIMES DISTRIBUTION
TRIALS: AS 45-84
(SD only)



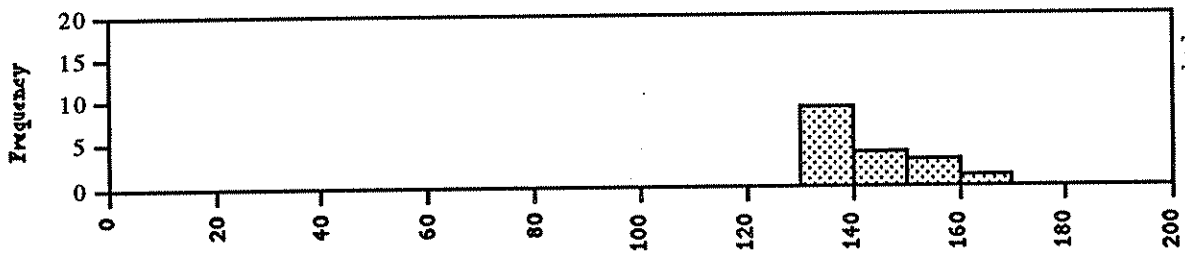
TIMES DISTRIBUTION
TRIALS: AS 85-124
(SD only)



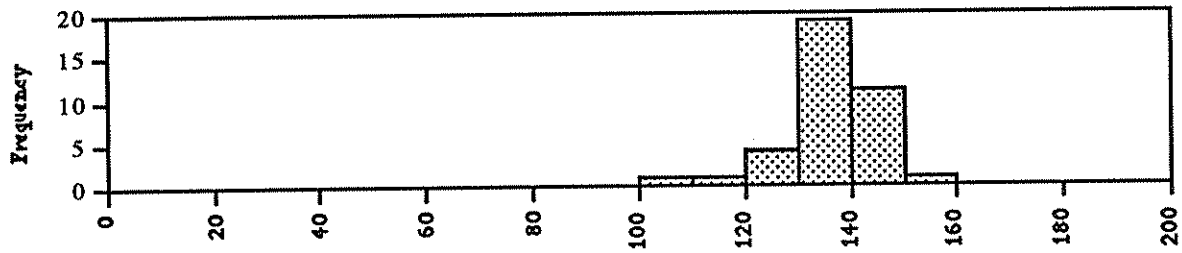
TIMES DISTRIBUTION
TRIALS: AS 125-165
(SD only)



TIMES DISTRIBUTION
TRIALS: AS 166-206
(SD only)



TIMES DISTRIBUTION
TRIALS: AV 23-44
(SD only)



TIMES DISTRIBUTION
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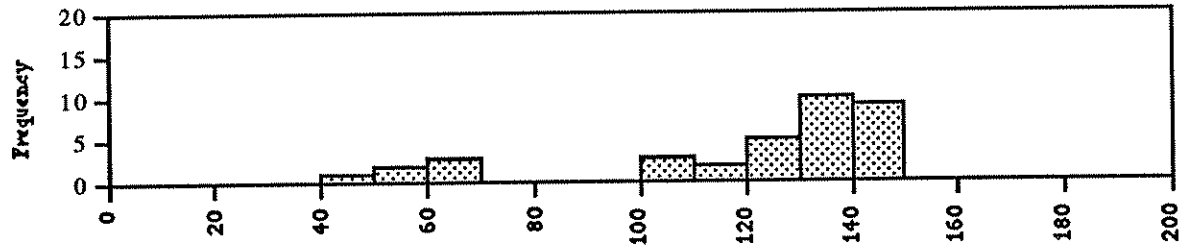
(SD only)



TIMES DISTRIBUTION
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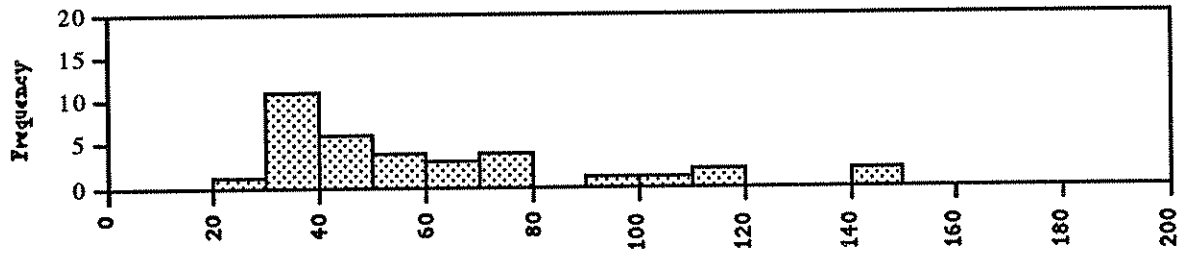
(SD only)



TIMES DISTRIBUTION
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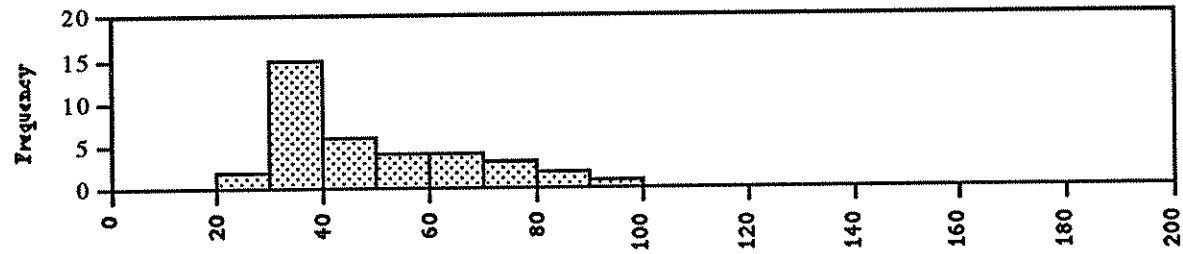
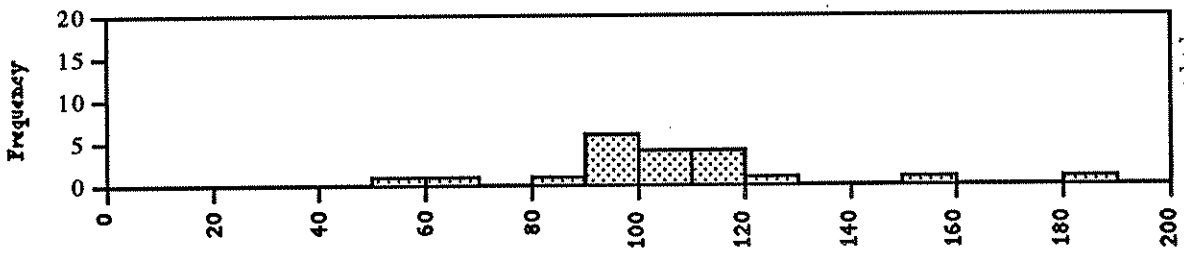
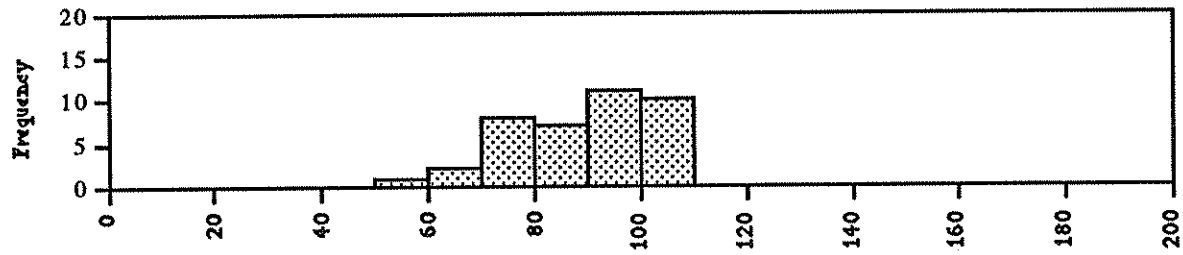
(SD only)



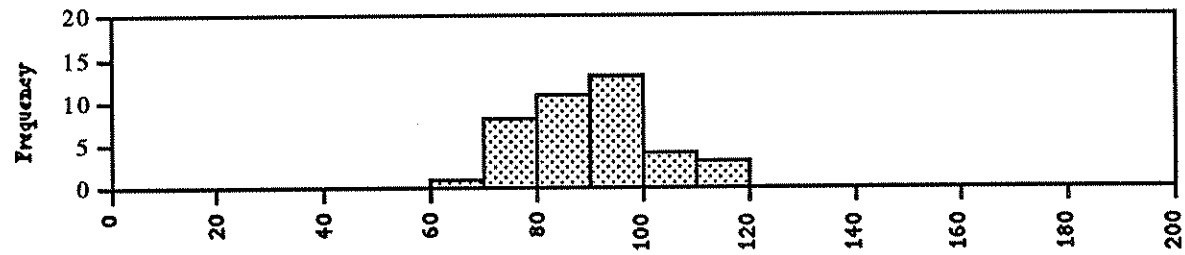
TIMES DISTRIBUTION
TRIALS: AV 166-206
(SD only)



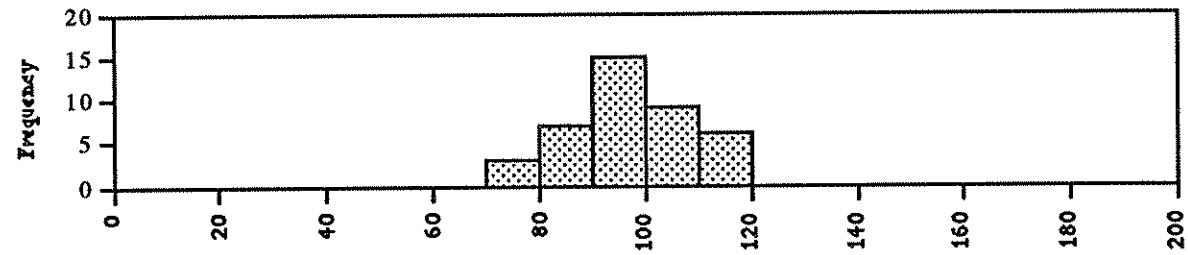
TIMES DISTRIBUTION
TRIALS: IS 23-44
(SD only)



TIMES DISTRIBUTION
TRIALS: IS 45-84
(SD only)



TIMES DISTRIBUTION
TRIALS: IS 85-124
(SD only)



TIMES DISTRIBUTION
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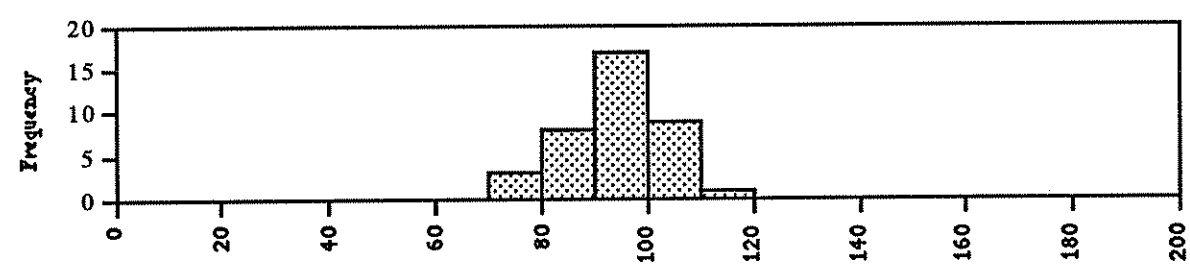
(SD only)



TIMES DISTRIBUTION
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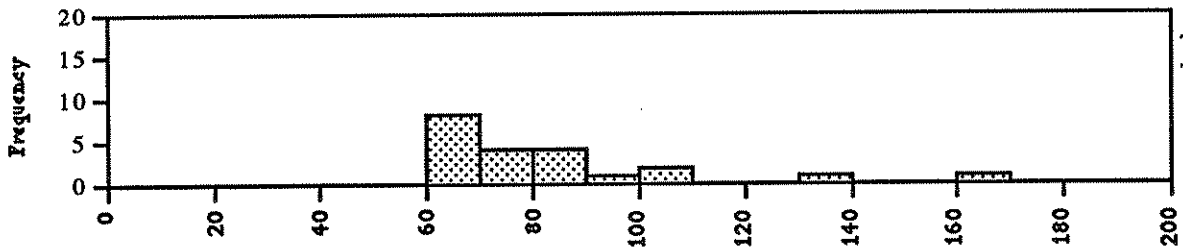
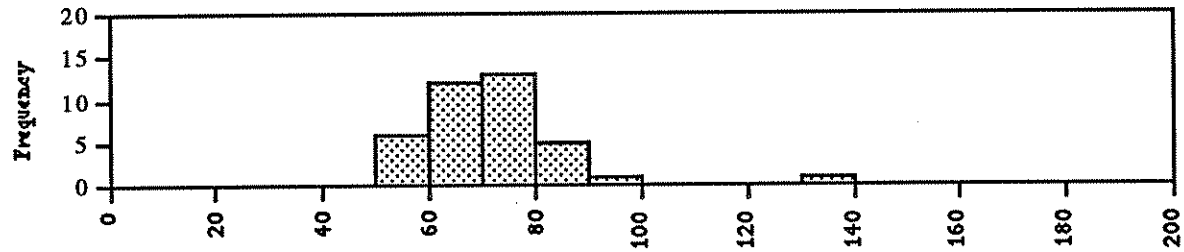
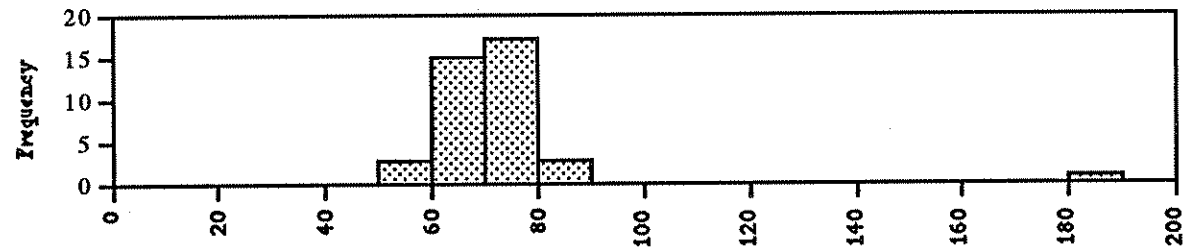
(SD only)



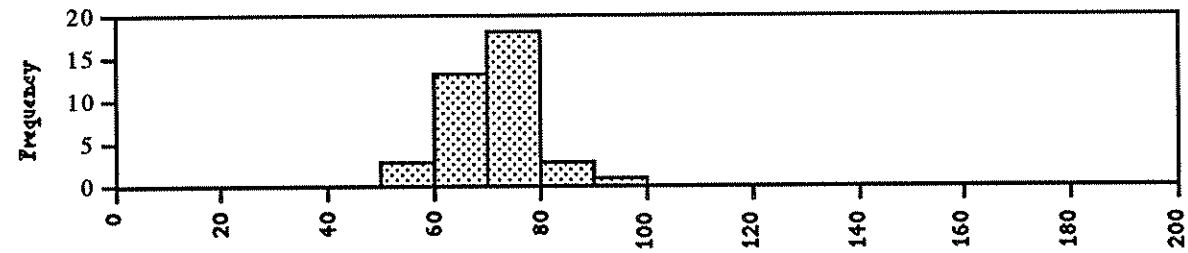
TIMES DISTRIBUTION
TRIALS: ML 23-44
(SD only)



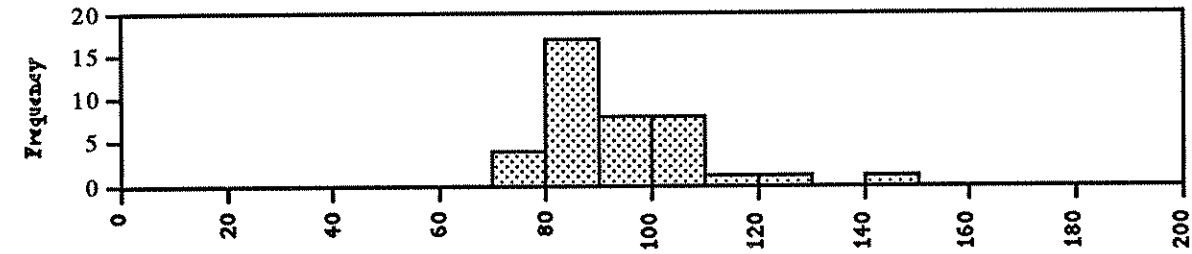
TIMES DISTRIBUTION
TRIALS: ML 45-84
(SD only)



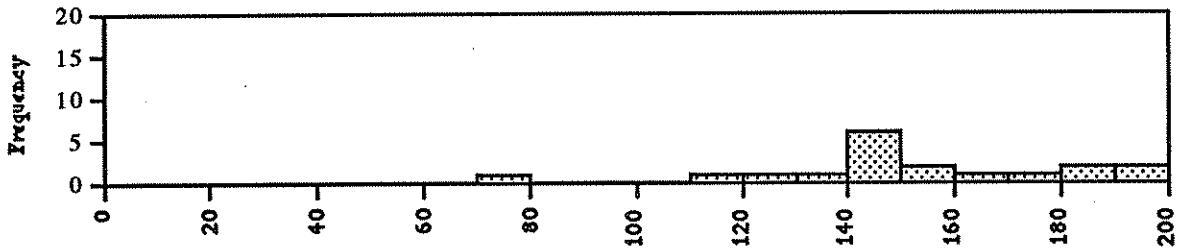
TIMES DISTRIBUTION
TRIALS: ML 85-124
(SD only)



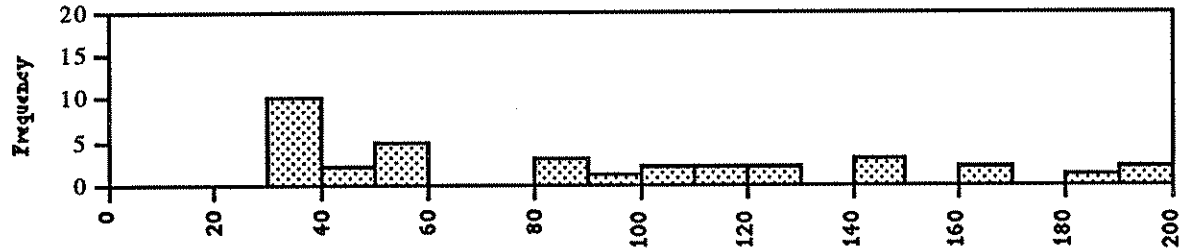
TIMES DISTRIBUTION
TRIALS: ML 125-165
(SD only)



TIMES DISTRIBUTION
TRIALS: ML 166-206
(SD only)



TIMES DISTRIBUTION
TRIALS: TL 23-44
(SD only)



TIMES DISTRIBUTION
TRIALS: TL 45-84
(SD only)

TIMES DISTRIBUTION
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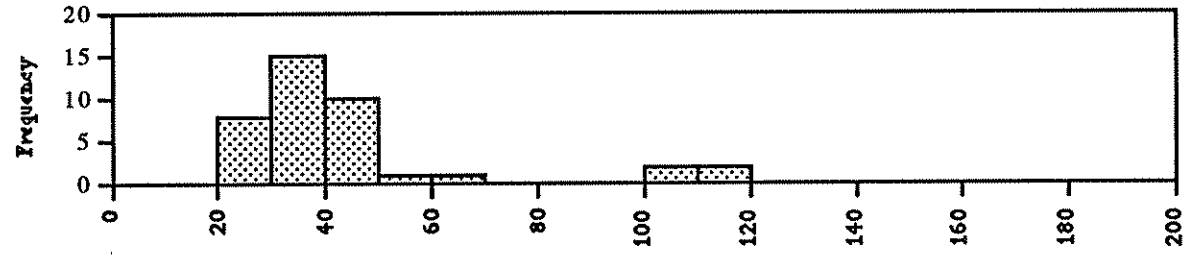
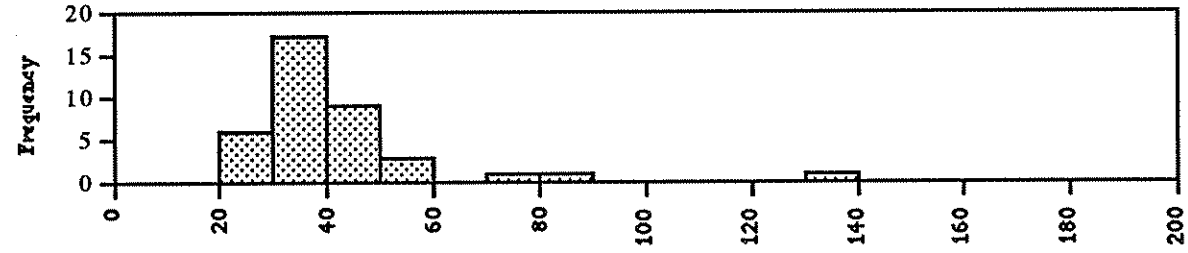
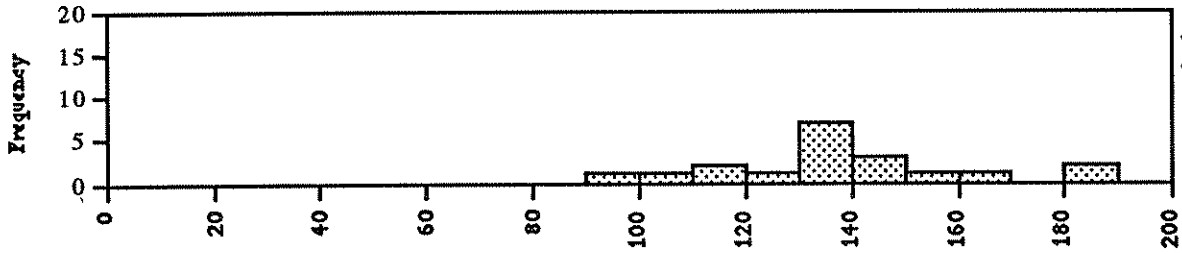
(SD only)



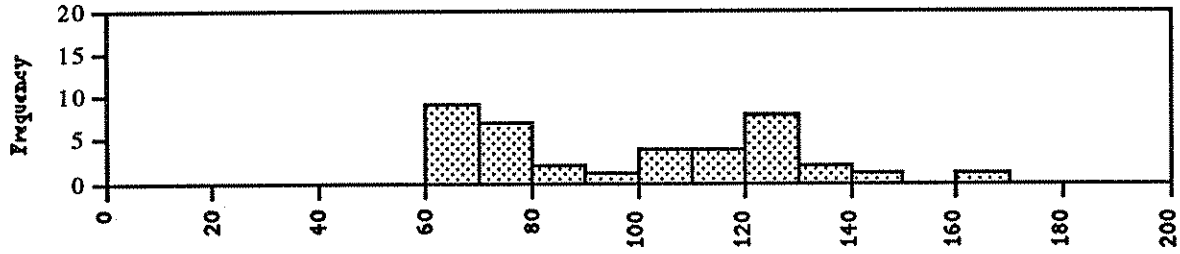
TIMES DISTRIBUTION
TRIALS: TL 125-165
(SD only)



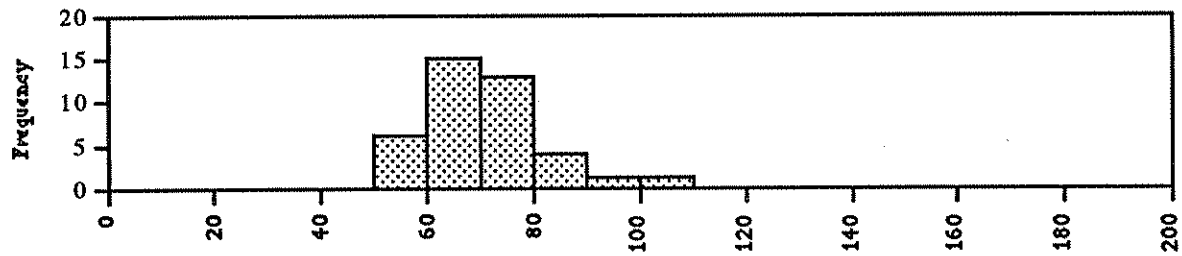
TIMES DISTRIBUTION
TRIALS: TL 166-206
(SD only)



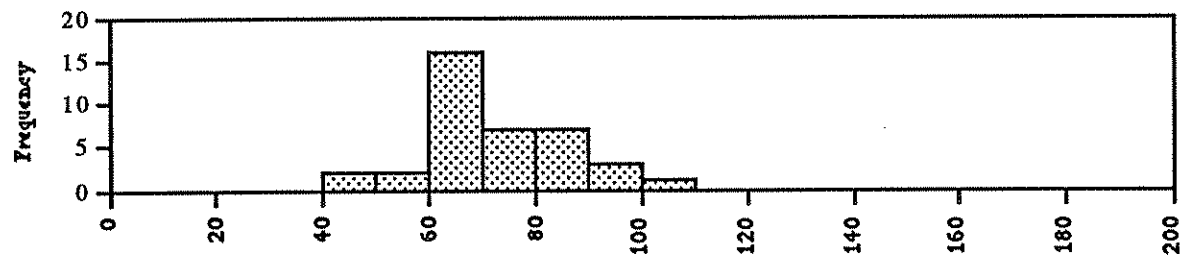
TIMES DISTRIBUTION
TRIALS: WL 23-44
(SD only)



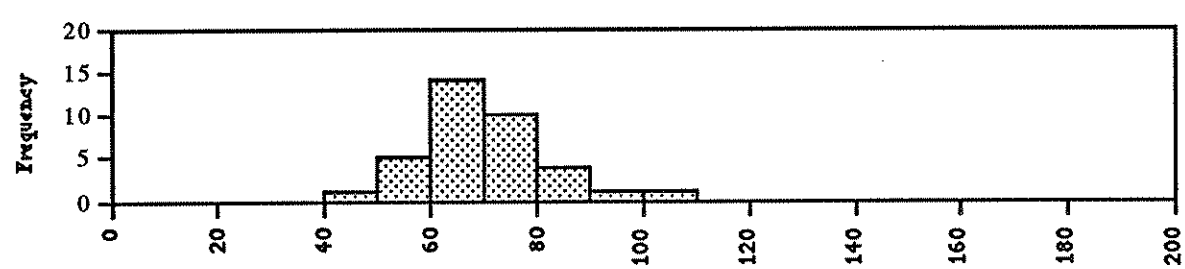
TIMES DISTRIBUTION
TRIALS: WL 45-84
(SD only)



TIMES DISTRIBUTION
TRIALS: WL 85-124
(SD only)



TIMES DISTRIBUTION
TRIALS: WL 125-165
(SD only)



TIMES DISTRIBUTION
TRIALS: WL 166-206
(SD only)

APPENDIX E:

Process Tracing Tables

This appendix provides a description of the coding scheme that was used to conduct the process tracing analysis of fault management behaviour, as well as the data analysis tables for all subjects for all fault trials that were analyzed. These tables are organized in sequence according to trial #, and then by subject group. A total of 54 tables are included (6 routine faults and 3 non-routine faults for each of 6 subjects).

Listed at the top of each data table is a short description of the fault and when it occurs within the trial. Also listed are the system output demands for that trial, as well as each subject's initials and interface group. Below this, a short description of the initial trial conditions is presented. This is used to provide the context for the information contained in the data tables. System state, and any other relevant subject control activity around the time that the fault occurred are presented. Additional information that may be relevant to the discussion of each subject's performance was included as needed. Experimenter notes are in italics.

In the interest of brevity, the data tables only contain actions, verbal protocol, and experimenter notes which are relevant to the detection, diagnosis, and compensation of the fault. In addition, this information usually only begins from the point at which the subject detects the fault. The only data that could be used for analysis were the subject's actions and verbalizations. Therefore, if the subject did not verbalize all of his thoughts, then the data collected will be an incomplete, conservative picture of the subject's cognitive activity.

The first column of each data table contains the time at which each control action or verbalization occurred. This time has been defined with respect to the onset of each fault so that comparisons can be made, not only across interface groups, but also across fault trials. Time is listed in minutes and seconds.

The second column, labeled detection, contains the subject's verbal protocol or experimenter notes that correspond to the subject's detection of the fault. Detection was defined using one of the following criteria:

- The subject says something which indicates that something abnormal is occurring within the system (e.g., "What was that?").
- The subject explicitly states that something specific about the system has changed in an abnormal manner (e.g., "There's a sudden drop of the water supply", "The water is strangely decreasing").
- The subject doesn't explicitly state that there is any sort of problem, but based on the control actions being made, it is easily identifiable that the subject is attempting to compensate for the abnormal system behaviour. This is identified by the subject acting upon the components of the system that are functionally affected by the occurrence of the fault. For detection to be scored in this matter, subjects must also verbally state at a

later time in the trial that they had detected the fault and were attempting diagnosis and/or compensation.

The third column, labeled diagnosis, uses two nodes of the decision ladder, observation and identification, for analysis. The data tables identify this information, which is always in the form of verbal protocol, with a letter "O" or "I," respectively.

The last column, labeled compensation, is broken down into three nodes of the decision ladder: Define a task, formulate a procedure, and execute a control action. These are identified by the letters "D," "F," and "E," respectively. "Defining a task" and "formulating a procedure" are typically accompanied by the subject's verbal protocol in the data tables. However, sometimes experimenter notes are listed in place of the protocol, especially if the subject provided a great deal of redundant protocol. Control actions relevant to fault compensation are identified by the letter "E." Again, if many redundant control actions occurred, such as the repeated manipulation of the heaters to maintain the goal temperatures, experimenter notes are presented in place of each individual action.

It is important to discuss the process of mapping the verbal protocol onto the categories of the decision ladder. Each item of verbal protocol was examined and, based on the definitions given below, mapped onto the relevant information processing nodes of the ladder. The examples below illustrate typical statements made by subjects during the trials and how these statements were mapped onto the decision ladder:

- ACTIVATION. The subject says something that indicates some sort of acknowledgment that the system has significantly changed (e.g., "There must be some problem").
- OBSERVE. The subject describes either a current system parameter or indicates that a change in a general system parameter has taken place (e.g., "Reservoir 1 is going down").
- IDENTIFY. The subject makes a clear statement about the current system state. This usually is identified as a statement about some higher-level system functional relationship (e.g., "I don't seem to be getting any flow from this line here").
- INTERPRET. The subject describes the effects that a control input or a procedure has had, or could have, upon the current and/or future state of the system (e.g., "Due to the leak in reservoir 2, the energy balance is no longer reliable").
- EVALUATE. This information processing activity was not observed in this experiment.
- DEFINE TASK. The subject states what needs to done to the system to reach some goal (e.g., "First I have to prevent this from overflowing (R2) and prevent this (R1) from running dry").

- FORMULATE PROCEDURE. The subject identifies a set of actions that need to be performed in order to accomplish a task (e.g., "The water level is up, so I will open the outlet valve").
- EXECUTE. This is usually only a control input, but it is sometimes accompanied by a verbalization (e.g., "I am increasing this (VA1)").

The summary section presented at the end of each data table is a qualitative interpretation of the entire trial. Subject control actions both before and during the fault are described, especially if these affect the interpretation of the data within the table. The second section after the table describes the subjects' post-hoc comments. Direct quotes are presented where relevant. Otherwise, the subjects' comments are paraphrased and discussed in light of their performance.

TRIAL #64

Summary: routine fault (valve)

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: IS
Interface: EID
Initial Conditions: System in steady-state. VA=10, VA1=3, VA2=8, VB=10, VB1=0, VB2=9, H1=3, H2=5, V1=60, V2=50.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:11	"OK, it appears that..."	I	"...pump 1 has failed."		
0:18				F	"So what I'll do..."
0:20				E	VB1 opened
0:24					"...is take up the slack from this pump..."
0:30				E	VB1 fine tuning
0:35				F	"...which means I'm going to have to put you (*VA2*) up."
0:48			"This is a toughie. How do I do this?"		
0:54				E	VA2 opened further (*to balance mass flow in R2*)
1:00				E	H2 decrease
1:04		I	"So it was valve A1... something's gone wrong"		
1:09		O	"That's (*mass input flow*) still too low."		
1:11				F	"Increase that (*VA2*) a little."
				E	VA2 opened further
1:17		O	"Got too much coming through VB1."		
1:18				E	VB1 decrease
1:19		O	"Temperature, fortunately..."		
1:21				E	H1 fine tuning
1:25		O	"...has not been decimated" (*i.e. still in goal region*)		
1:27				F	"Increase the water to reservoir 2 through VB2 just a little bit."
				E	VB2 increase
1:40				E	VB2 fine tuning
			"So now... I certainly didn't expect that."		

Comments: He did not perform any actions between the time of the fault and the time at which he detected it, indicating that he was able to detect the fault in an

open-loop manner as opposed to discovering the problem as a result of actions which did not produce the expected results. He immediately begins to compensate, attempting to stabilize volume. Through his compensation actions, he infers that it must have been VA1 rather than PA that failed, likely because he realizes that water is still flowing through VA2. He specifically chose to restabilize volumes before attempting to address the temperatures.

Post-hoc: No post-hoc comments.

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: AS
Interface: EID
Initial Conditions: System in steady-state. VA=10, VA1=2, VA2=9, VB=10, VB1=2, VB2=10, H1=4, H2=6, V1=60, V2=60.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:03	"The water level's changing (*in reservoir 1*). That's interesting, why is that happening?"				
0:10				E	VO1 decrease slightly
0:11			"How come the water level's changing?"		
0:15				F	"I'll do it (*VA1*) higher"
				E	VA1 increase
0:24				F	"Lower this one" (*VA2*)
				E	VA2 decrease
0:44				E	H1 fine tuning
0:47				E	VA1 opened fully
0:50				E	VA2 decrease further
1:01		O	"That's interesting... I don't know what's going on here."		
1:09				D	"I need more water..." (*in reservoir 1*)
1:13				E	VA1 increase, decrease, increase, set back to original level
1:20			"Hellloooo..." (*to VA*)		
1:21				E	VA1 jostled again, this time left at fully open
1:28				E	VA2 closed
1:43			"Can I ask for help?"		
1:50		O	"The pump is on and there's no water. Is that normal?"		
2:04					**PA blows up**

Comments: The subject realized that the problem was that there was not enough flow through VA1 and tried to compensate by increasing the setting of VA1 and decreasing that of VA2. When this did not work, he became confused and asked for help. He did not have any ideas about why the system was

behaving as it was. Although he had clearly observed the relevant symptoms, he was apparently unable to conceive of a possible root cause.

Post-hoc: "I don't know what's going on. This level (*points to VA*) was dropping. Now I really have to think... that's bad. I don't think I did something wrong. Assuming the program is robust, it can only be due to human error." It is perhaps illuminating to note that AS prefers not to have to think about what is occurring in the system.

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: AV
Interface: EID
Initial Conditions: System in steady state. VA=10, VA1=5, VA2=10, VB=10, VB1=0, VB2=10, H1=3, H2=6, V1=20, V2=15.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:02	"Whoa, woo woo... what the hell was that?"				
0:06				E	VB2 decrease (*because all flow from VA is now going to R2*)
0:16				E	VA2 decrease
0:20	"This is stupid! Come here! (*to E*)"				
0:23				E	H1 decrease (*V1 was getting low, so T1 was rising quickly*)
0:34		O	"Why does it do that... there's nothing coming out here (*points to VA1*)... shit, why did it do that?"		
0:43				E	H1 turned off
0:44				E	H2 decrease
0:46				E	VA1 opened fully
0:47		O	"Why there's no water coming through over here (*VA1*)... this fall down (*flow rate on VA*)... the water here fall down to half."		
0:56		O	"The valve (*VA*) is wide open, this (*PA*) is on..."		
1:05		I	"There's not water enough here (*points to the left of the input water temperature gauge (T0), where water enters the system*)... there's supposed to be enough water to cover the demand here."		
		O	"Ah, I cannot do that." (*meet the demand in reservoir 2*)		
1:23				E	VB2 increase to 10
		O	"Is this natural? This (*input*) is supposed to have enough water... it doesn't give enough water. There's something wrong with the program."		
1:30				E	VO1, VO2 closed

1:31		O	"This doesn't work out... this (*VA1*) is open, this (*VA*) is open, this (*VA2*) is half open... I have water here (*flow rate on VA2*) but I don't have water over here (*flow rate on VA1*)."		
5:48					**R1 heated empty**

Comments: The subject immediately identifies that something is unusual about the flowrate through VA1. Because one of his initial compensation actions was to decrease VA2 to a setting of 5, the flowrate through VA also dropped to 5, leading him to incorrectly conclude that only 5 units were available from FWS A and that for some reason all of the flow was going through VA2 rather than VA1. He seemed to become fixated on the idea that there was not enough source water available to meet the demand rates. As a result, he was not able to formulate any alternative explanations for the system's behaviour, despite clearly making note of all the symptoms. He either did not realize that he could use VB1 to add flow to R1, or simply chose not to because he thought that doing so would make him unable to meet the demand rate for R2. Thus, he allowed R1 to drain completely and although H1 had been turned off, it had not been off for a sufficiently long period of time, causing the system to fail because R1 was heated empty.

Post-hoc: Subject stated that he believed there was not enough input water at the source to meet the output demands and that PA may have been malfunctioning.

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: TL
Interface: P&ID
Initial Conditions: System in steady-state. VA=10, VA1=3, VA2=6, VB=10, VB1=0, VB2=10, H1=3, H2=5, V1=70, V2=60.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:32	"What the heck... I'm not quite sure what happened there."				
1:01				E	VA1 increase slightly (*to compensate for decreasing volume in reservoir 1*)
1:10		I	"I see, the extra demand from pump A... the gauge on VA1 is not that accurate."		
1:42				E	H2 decrease
1:53				E	VA1 increase further
2:06				E	VA2 decrease
2:11				E	VA1 decrease
2:34		O	"Not quite sure why reservoir 1 is still draining... should be at least 5 going into there." (*because VA1 is currently set to 5*)		
2:58				E	VA2 decrease slightly
3:00				E	H2 decrease
3:26				E	VA1 opened all the way
3:27				E	VA2 closed
3:40				E	H2 fine tuning
4:02					**PA blows up**

Comments: Note that subject was already using the demand-rate/heater-setting rules of thumb (i.e., set H1 to level equal to D1, set H2 to level equal to one-third of D2). Subject was performing fine tuning on VA1 right before the fault occurred. He then began also to tweak H1 because the temperature was rising in reservoir 1. At approximately 0:20 after the fault he turned H1 off because of the continued rise in T1. He then verbalizes the fact that something doesn't seem right, presumably because of T1's behaviour and the fact that volume is decreasing in reservoir 1. He tries to compensate by opening VA1 further, noting that perhaps the gauge is inaccurate. He

seemed to believe that there was something wrong with the way the flows were being split between VA1 and VA2 and eventually closes VA2 completely, likely to try to get more of the available flow to go through VA1, thereby causing PA to fail.

Because no diagnostic information is available to the subject, he cannot make an accurate assessment of the reasons for the system's behaviour. His response is to make incremental changes to the component settings to try to compensate. When these fail to have the desired effects, his suspicion that something is wrong is strengthened but he is unable to make a firm conclusion about what the problem is.

Post-hoc: Subject noted that VA1 was "acting closed." He was not able to offer any further elaboration.

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: WL
Interface: P&ID
Initial Conditions: System in steady-state. VA=10, VA1=2, VA2=8, VB=10, VB1=1, VB2=8, H1=3, H2=5, V1=50, V2=60.

Comments: Subject did not make any relevant verbalizations between occurrence of fault and end of trial. He seemed to notice that the temperature in reservoir 1 was acting strangely and began adjusting VA1 to try to get volume stabilized. By 1:30, he had VA1 set at 10. He briefly tried turning VB1 up to 10 but quickly turned it back down; it wasn't open long enough for him to discover that this would have had a direct effect on the status of reservoir 1. He essentially tweaked the system continuously until the end of the trial in order to maintain steady-state, and was able to successfully complete the trial.

Post-hoc: Subject stated "It was more difficult; it took a long time" but did not offer any reasons for why this was the case or what might have caused it to be more difficult.

Trial: 64 (start-up only)
Fault: VA1 becomes blocked 4 minutes after start of trial (D1=3, D2=16)
Subject: ML
Interface: P&ID
Initial Conditions: System in steady state. VA=10, VA1=4, VA2=8, VB=9, VB1=0, VB2=9, H1=3, H2=5, V1=20, V2=30.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:54	"This is stupid... why is this (*V1*) going down? I haven't changed anything."				
1:03				E	VO1 closed
1:10		O	"This (*V2*) has gone way up."		
1:20		O	"I've got this (*VO1*) set at zero, there's water feeding to it (*R1; points to VA1 implying that he thinks there is water flowing into R1 through it*)... it's not doing anything." (*i.e., V1 is not changing*)		
1:30		O	"This one (*V2*), water's going way up."		
1:34		I	"There's no water going into it (*R1*)... why? Why is there no water going into it?"		
1:41		I	"Is it this?" (*points to VA1*)		
1:51				F	"Let's open this (*VB1*) up, see if it helps."
1:55				E	VB1 opened to 5
1:59		O	"Oh yeah, water's going in there." (*into R1*)		
				E	VB1 closed
2:10			"Is something supposed to go wrong on this?"		
2:36				F	"Let's put some water in." (*to R1*)
				E	VB1 opened to 3
2:45				F	"Turn this (*VA1*) off..."
				E	VA1 closed
		0	"... since apparently it makes no difference." (*referring to VA1*)		
2:54				E	VO1 re-opened
3:00				E	H1 increase to 5

3:30		I	"I guess I'll just ignore this (*VA1*)... assume this is broken or something."		
3:36				E	H1 decrease
3:39				E	H1 turned off (*because T1 is rising very quickly*)
3:46				D	"I'm going to make it blow up so I don't have to deal with it... since this isn't real." (*joke*)
4:02				E	VB1 increase
4:15				E	VA1 opened
4:26		O	"I've opened this (*VA1*) but it's not making a big difference here (*V1*)."		
4:34				E	VA1 closed
				E	VA2 opened fully
				E	VB2 decrease (*these three actions represent a reconfiguration of the valves to suit the situation*)
5:12		O	"This (*V1*) is rising a little... it's at 9, 10. This (*V2*) is at 16... 16 and going down; (*points to V1*) 9,10 and rising."		
5:30				E	VB1 decrease
5:32				D	"... see if we can get the fucking water level to stabilize."
5:40		O	"11 (*points to V1*), 13 (*points to V2*)"		
6:00				E	fine tuning heaters
7:00				E	fine tuning valves
11:50		O	"Water seems to have stabilized."		

Comments: The subject detected the fault through the unexpected change in the volume level of reservoir 1. Because VB1 was closed, he was able to make a correct initial guess that the flow through VA1 had dropped. By experimenting with the valves in a trial and error manner he seemed to confirm his guess and identify a method of compensation. He had some difficulty in stabilizing the water levels, presumably because he was unable to use his customary strategy, but eventually he was able to reach steady state.

The subject commented several times that he wished to leave, that he wished the trial was over, and that he was becoming frustrated.

Post-hoc: When the trial was complete the subject left the room quickly, commenting "It was one where something went wrong."

TRIAL #94

Summary: routine fault (reservoir leak)

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: IS
Interface: EID
Initial Conditions: System in steady state. VA=10, VA1=4, VA2=3, VB=10, VB1=0, VB2=8, H1=2, H2=4, V1=35, V2=30.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:11		O	"Oh dear, water level drop."		
0:14				E	VB2 increase (*to increase flow to R2*)
0:18				E	VB2 increase
0:31				E	VO1 fine tuning
0:40			"Hmmm..."		
0:44				E	VA2 increase
0:52				E	H1 fine tuning
0:54				E	VA1 increase
1:08		O	"Something odd is happening but what it is I haven't a clue."		
1:19		O	"OK, that's fine." (*points to H2*)		
1:34		O	"I'm puzzled by (*the behaviour of R2*)... because water is coming in from both of those... (*points to VA2, VB2*) ...but for the life of me I can't figure out why..."	E	H1 fine tuning
1:39		O	"The amount (*volume*) in reservoir 2 is just not going up."		
1:48		O	"Nor is the heat going up... (*points to H2*)... very odd." (*He may have been expecting T2 to rise because V2 was decreasing, but T2 did not rise*)		
1:50				E	H2 fine tuning
1:53				E	H1 fine tuning
2:00				E	VA2 increase
2:06			"There we go..." (*possibly referring to V2 becoming stable again*)		
2:10				E	VA2 increase
2:23				E	VA2 fine tuning
2:24				E	H1 fine tuning

2:30				E	H2 increase
2:33		O	"Now (*unintelligible*) the temperature's up."		
2:43			"Well, I think I can safely say that I blew this one quite admirably."		
2:51				E	H1 decrease
2:53				E	H1 decrease
2:55				E	H2 decrease
2:58				E	H2 decrease
3:00			"It was going quite well, too."		
3:05			"I can't for the life of me..." (*Subject is still trying to think of a reason for the system's behaviour*)		
3:08				E	H1 decrease
3:10				E	H1 decrease
3:13			"I cannot figure out..."		
3:18				E	H1 decrease
3:21			"...what went wrong."		
3:30				E	H2 fine tuning
3:36				E	H1 fine tuning
3:40			"I've got no indication why..."	E	H2 decrease
3:47				E	H2 increase
3:51				E	H2 fine tuning
3:55			"Hmmm..." (*inflection suggests he has discovered something interesting*)		
4:00				E	H2 increase to 10
4:03				E	H2 decrease to previous setting
4:13		O	"That's in the middle (*i.e., T2 is in the center of goal region*)..."	D	"...keep an eye on that (*status of T2*)
4:25				E	H2 fine tuning
4:30				E	H1 increase
4:47		O	"Still in the middle." (*referring to T1*)		
5:08			"Well, I'm trying to figure out what happened... I haven't a clue."		
5:20			"OK, the gauges don't lie."		

5:30				D	"Oh well, it's stable so I'll just wait for the settings to change then."
6:26			"I suspect it's going to be a long wait considering how long it took me to get stable."		
6:57			"Mind you, I don't have so many minutes to wait."		
7:07		O	"Considering the rate at which reservoir two is filling up... oh, there we go (*likely referring to a small change in T1*)		
7:12				E	H1 increase
7:15		O	"The temperature in reservoir one dropping slightly..."	F	"...so increase the heater (*H1*) setting."
7:20				E	H1 increase (*3 times*)

Comments: The subject detected the fault almost immediately and quickly identified most of the relevant symptoms. He was not, however, able to identify the fault, and his compensation procedure therefore consisted of incrementally changing the system component settings until the system had stabilized. He seemed to believe that the gauges might be incorrect, but he knew that this conflicted with the information he had been given at the outset of the experiment. Once the system had stabilized again, he appeared to be satisfied to simply wait until the setpoints changed, in spite of the fact that he was unable to identify a reason for the system's behaviour. In the post hoc interview, he does in fact suggest that the problem may have been a leak in R2, but did not seem confident that such a suggestion is even plausible.

Post-hoc: "I could not pinpoint the problem... the only thing I could think of was that the gauges weren't telling me the truth." Subject recalled being told however, that the "flow gauges" are always accurate. He thought R1 was "fine". With respect to R2, he stated that "according to the graph (*the mass balance graphic for R2*)... when input equaled output, the level (*V2*) was dropping like a stone... so I had to increase input to make up for it... I use the gauges (*points to the mass and energy balance graphics; likely referring to the input and output flowrate indicators*) more than anything else, so I was thrown by the fact that input was very much higher than output yet the reservoir volume (*V2*) stayed pretty stable. So I think the reservoir had a leak (*laughs to himself as though he believes he has said something ridiculous*)... other than that I can't think of anything else... I had to compensate with the heater as well. I had to set the heater at a greater input

energy than output energy." He thought the heaters were acting "sluggish" and stated that this also suggested to him that there was something wrong with the system, but that he could not figure out "exactly what was wrong."

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: AS
Interface: EID
Initial Conditions: Output and temperature in goal regions but temperatures not yet stable. VA=8, VA1=3, VA2=10, VB=8, VB1=5, VB2=10, H1=7, H2=5, V1=50, V2=60.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:38			"It's now in steady-state."		
1:29		O	"For some reason the water level in reservoir two is dropping."		
1:35				F	"I'm going to close the valve." (*VO2*)
1:36				E	VO2 closed
1:39			"I don't know why this is happening..."		
1:47			"...but weird things have happened before. I guess this is one of them."		
2:00				F	"OK, now open the valve (*VO2*) again."
2:00				E	VO2 increase to demand value
2:24		O	"So right now the two flowrates (*input to R2 and output from R2*) appear to be identical... but the water level is dropping for some unknown reason."		
2:24				E	VO2 fine tuning
2:40				E	VA increase to 10
2:42				F	"That's why I'm going to increase... " (*likely referring to the input to reservoir 2*)
2:49			"This is very strange."		
3:00				E	VA1 decrease
3:18		I	"There must be a leak somewhere (*circles R2 with pointer*), it doesn't make sense."		
3:19				E	H1 fine tuning
3:22				E	VA1 fine tuning
3:30		O	"Water level is still dropping (*in R2*)."		
3:35				F	"I'm afraid I have to close this valve (*VO2*) again."

3:36				E	VO2 closed
3:45				E	H1 fine tuning (several times)
3:50				D	"Still trying to stabilize water (*unintelligible*), although the other one (*R2*) is having weird behaviour."
4:00				E	H1 fine tuning
4:20		O	"OK, it's half full now..." (*i.e., V2=50*)	F	"...I'm going to try it again... open up the valve (*VO2*) to the setpoint."
4:22				E	VO2 increase to demand value
4:41				E	VO2 fine tuning
4:51				E	H2 fine tuning
4:55		O	"See, right now the input flowrate (*to R2*) is actually larger than the output flowrate;...water should accumulate in the tank but instead water level's dropping... with no apparent reason."		
5:15				D	"Pump more water in here (*R2*) and see what happens."
5:16				E	VA increase to 10
5:30				E	H2 fine tuning
5:30		O	"OK, it's stabilizing now." (*V2*)		
5:36				E	VA decrease
5:51				E	VA1 fine tuning
6:01				E	H2 increase
6:16				E	VA1 fine tuning
6:20				E	H1 fine tuning (several times)
6:51		O	"OK, reservoir number one has been stabilized."		
6:58		I	"OK, reservoir number two, as you can see, the water level is not dropping but the input flowrate is larger than the output flowrate so there must be a leak somewhere here in the reservoir (*points to R2*)... it doesn't make sense."		

7:18				D	"I'm still increasing temperature in tank number two... just to get the red mark in the green region." (*the context-free language he uses to describe the temperature indicator and the temperature goal region suggests he is highly attuned to the perceptual features of the display*)
7:30				D	"I'm leveling it off." (*likely referring to the setting of H2 - he intends to return it to the setting he would expect to use given the demand flowrate in R2*)
7:32				E	H1 fine tuning
7:33				E	H2 fine tuning
7:58				D	"I'm not leveling it off anymore because there's water constantly going in (*to R2*), coming out (*from R2*)."
8:00				E	H1 fine tuning (several times)
8:58			"This is really weird."		
9:16		O	"See this (*T2*) is dropping right now even if there are more heat going into the reservoir (*i.e., the energy input to R2 is greater than the energy output*)... which again doesn't make sense."		
9:25		O	"I'll just leave it at that. I'm assuming the system is in steady state now (*despite the unusual behaviour of R2*). I don't know what that means any more."		
9:41				D	"Doing some fine adjustment."
9:43				E	VO2 fine tuning
10:00				D	"I'm waiting for the setpoints to change now. It's going to take a while. Twelve minutes already. I can't believe that."
10:26				D	"Doing some fine tuning."
10:27				E	H2 fine tuning
11:20				D	"Still waiting for the setpoints to change... hopefully then the system will go back to normal (*he thinks the problem in R2 will correct itself when the setpoints change*)."

Comments: Once the subject detects the fault, he initially attempts to accumulate water in the reservoir by closing VO2. When he re-opens VO2 he pays close attention to the relation between the input and output flowrates in R2. When

he realizes that there is a mismatch between the two in spite of the fact that they are indicated to be equal, he correctly concludes that there must be a leak in R2. Thus, the subject detected the fault, made an initial attempt to compensate, and then through the system's response to his control actions, was able to make a diagnosis. He seemed unsure of his diagnosis at first. It was not until he had stabilized the volume level in R2 and could clearly see that the necessary input flowrate was larger than the output rate that he seemed confident about his assessment of the system.

With respect to the energy balance, he seems to independently go through the same process as he did with the mass balance when he attempts to stabilize temperature in R2. He seems to attempt to match the energy input with the indicated energy output but discovers that this causes T2 to decrease. He seems then to realize that this is related to the situation of the mass balance and compensates accordingly. As alluded to in the remarks above, it is interesting to note the language the subject uses when he describes his actions as he attempted to re-achieve the temperature goal in R2. He says "I'm still increasing temperature in tank number two... just to get the red mark in the green region." This comment seems to indicate an apparent dependence on the perceptual, surface features of the display.

Post-hoc: "I think there is a leak somewhere in reservoir two because... the input (*flowrate*) has to be larger than the output just to keep the water level steady (*in R2*)... To compensate I just increased the flowrate here (*points to input flowrate indicator for R2*)... and increased the heater just to keep this bar (*T2*) in the middle (*of the goal region*)... just doing some eyeballing." Subject stated he just kept increasing flowrate incrementally until the water level stopped dropping. He also noted that he was "expecting" the system's behaviour, by which he meant that he didn't mistake it for an error in the simulation software, and therefore proceeded to attempt to compensate for it rather than calling the experimenter over as he did during the first fault trial.

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: AV
Interface: EID
Initial Conditions: System in steady state. VA=10, VA1=4, VA2=1, VB=10, VB1=0, VB2=10, H1=5, H2=4, V1=15, V2=15.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:26	"What?!"				
0:28				E	VA1 increase to 10
0:30			"Oh come on!"		
0:32				E	VO1 fine tuning
0:42				E	VO2 closed
0:45		I	"I think there's something wrong here."		
0:49		I	"It did it again. Do you (*to experimenter*) remember the other time (*referring to previous fault trial*) the water disappeared from the tank? It did it again. The water disappeared (*from R2; the water completely emptied from the reservoir*)."		
0:55				E	VO2 increase to 11
1:00				E	H1 increase to 10
1:05		O	"The water disappeared from the tank (*R2*)... this is almost half for him (*R1; i.e., R1 is half full*)... this one (*R2*) is almost empty... this is stupid."		
1:16				E	VA1 set to 3
1:20		O	"There it goes again! See that? See it? How come?" (*referring to fact that R2 has drained completely again*)		
1:30				E	H1 decrease
1:35			"Jesus Christ!"		
1:37				E	VO2 closed
1:40				E	VA1 increase to 4
1:48				E	VA1 increase to 5
1:52				E	VO2 opened to setpoint value

1:53		I	(*Experimenter: "What do you think is happening?"*) "What do I think is happening? The thing just disappeared! You saw it, the water just disappeared from here (*R2*). There was water here (*R2*) and then it was gone." (*Experimenter: "Why?"*) "I don't know, there's a hole in the tank (*R2*), I don't know... god damn it!"		
2:08				E	VA1 decrease
2:13			"Are you guys pulling a prank on me or something?"	E	VA1 decrease
2:14				E	H1 increase
2:25			"There it goes again! (*R2 has drained completely once again*) Here, see it? The water (*in R2*) disappeared."		
2:30				E	VO2 closed
2:40			"Is this supposed to happen?"		
2:42				E	VO2 opened to 12
2:50				E	VA1 increase
2:53				E	H1 fine tuning
3:00				E	VO2 decrease
3:05				E	VO2 increase to demand value
3:06				E	VO2 closed
3:12				E	VO2 opened and closed quickly
3:18				E	VO2 increase to demand value
3:35				E	H1 fine tuning
3:39			(*R2 empties once more*) "There it... come on, I'm getting pissed off now! Jesus Christ, why does this thing happen all the time?"		
3:46				E	VO2 opened and closed quickly
3:49				E	VO2 increase to demand value
4:04				E	VA2 increase
4:10			"I've had enough." (*Subject gives up.*)		
4:15				E	VA2 increase
4:24			"Could somebody explain me something? Why this thing (R2) doesn't get water in there?"		

4:30					**R2 heated empty**

Comments: Although the subject detected the fault fairly quickly, he was unable to successfully compensate because he insisted on attempting to follow his regular procedures (see post-hoc comments). Each time reservoir 2 drained, he attempted to build up water in the reservoir by closing the output valve. Once some water had accumulated, he would then open up the output valve again, attempting to achieve equal input and output flowrates (and thus making the line connecting the input and output flowrate indicators vertical). He was unable to overcome this fixation on the slope of the line in the mass balance graphic, and kept trying to ensure that it was vertical, in spite of the fact that the reservoir continued to drain when he had achieved a vertical slope. He went through this pattern 5 times during the trial. During the post hoc interview, he specifically noted that there may have been a hole in the reservoir. He also suggested this during the trial but it seemed his fixation on ensuring that the indicated input and output flowrates were equal dominated his attempts to compensate. He did not attempt to increase the input flow to R2 until very late in the trial and seemed to give up before he realized that this would have helped to solve the problem.

Post-hoc: The subject was very agitated after the trial. When asked what happened, he said: "The water disappeared, there was a hole in it (*referring to R2*). You guys fixed (*i.e., planned*) it. Either that or your program is shit, take your pick. I did everything I'm supposed to do (*i.e., he was following his usual procedure*) and the water disappeared!" He stated that he was trying to use the output valve (VO2) to build up water in the reservoir by closing it, but that the water kept "disappearing".

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: TL
Interface: P&ID
Initial Conditions: Mass and energy in goal regions. VA=10, VA1=6, VA2=2, VB=10, VB1=0, VB2=10, H1=5, H2=4, V1=50, V2=50.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:05				D	"Things are filling up pretty slowly so better increase the volume here" (*R2*)
1:10				E	VA2 increase
1:11				D	"And likewise better increase the temperature (*T2*) also."
1:32				E	H2 increase
1:44				E	VA2 increase
1:45	"Sure is increasing slowly here (*V2*)... in fact I think we're losing ground in reservoir two. I'm not quite sure what's happening... just keep a closer eye on things."				
1:58				E	H2 increase
2:09				E	H1 decrease
2:11				E	H2 increase
2:14		I	"Things are filling now (*in R2*), temperature's (*T2*) still dropping though... I think we've averted any disaster now."		
2:32				E	H2 decrease
2:35		I	"Woo... overdone it a little bit (*T2 was getting too high*)... still no disaster."		
2:35				E	H2 decrease
2:58		O	"So input's around fifteen..."		
3:00				E	H1 set to 4
3:01				F	"...so put it (*H2*) at about five for reservoir two, put it (*H1*) at about four for reservoir one." (*Subject appears to be setting heaters according to his rules.*)
3:05				E	H2 set to 5
3:24		O	"It's getting a little cool in reservoir one (*i.e., T1*)..."	F	"...so pump it (*H1*) up a little bit."

3:26				E	H1 increase
3:45				E	H2 fine tuning
3:50				E	H1 decrease
4:02				E	H1 decrease
4:05		O	"It's getting a little too hot in reservoir one. Not quite sure why it's so hard to keep things under control."		
4:30			"Coming up to the point where I've got to look at changing the demand pretty soon."		
4:38				E	H2 fine tuning
5:15			"Surprised the change in demand hasn't come already... hope I haven't screwed things up somewhere along the way."		
5:50			"Pretty surprised to see what's happening here (*referring to fact that setpoints have yet to change*)... didn't think it was that late."		

Comments: He was gradually filling up the reservoirs (intentionally) when the fault occurred. This is likely related to his shutdown strategy, which relied on having high volumes in each reservoir when the tuning phase began. This caused him to notice the fault through the fact that reservoir 2 was not filling up as fast as he expected it to. Thus, this violation of the expected progress of his procedure (see post hoc comments) was responsible for his detection. He did not have any specific ideas about what was wrong with the system, stating only that it was behaving a little strangely. He did not even attempt a diagnosis, likely because he had no explicit information available around which to organize his observations of the system's behaviour.

Post-hoc: The subject knew that there was something unusual happening because he had to keep more water going into reservoir 2 than he expected. He stated that he did not have any idea of what was happening to make the system behave as it was, though. He stated that he just went about compensating incrementally through a trial and error method and was just "reacting" to reservoir two's behaviour. He explicitly stated, in the course of recounting the trial, that he normally employs a "pattern" or "protocol" for starting up the system and maintaining steady state. When asked what he thought was happening in the system, he simply stated: "I don't know."

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: WL
Interface: P&ID
Initial Conditions: System in steady state. VA=10, VA1=2, VA2=6, VB=10, VB1=2, VB2=6, H1=0, H2=0, V1=60, V2=70.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:36	"Now I see the water level dropping in reservoir two, so we have to check the (*input*) level."				
0:45		O	"Five, five (*referring to settings of VA2, VB2*)... seems correct."		
0:47				E	H2 turned off
0:49				E	VB2 increase to 10
0:50				E	VB increase to 10
0:58				E	VB2 decrease to 6
1:05				E	VB2 increase to 7
1:06				E	VA2 increase to 8
1:13				E	H1 increase to 10
1:18		O	"Open the other one changes the... second one." (*likely referring to fact that manipulating the valve settings causes changes in both reservoirs; this is a direct result of his fully coupled valve configuration strategy*)		
1:20				E	H2 increase to 10
1:31				E	H1 turned off
1:41				E	H2 turned off
1:55				E	VA2, VB2 fine tuning
2:08				E	H2 increase to 10
2:15				E	H1 increase to 10
2:44				E	VO2 closed
2:49				E	VO2 increase to demand value
2:50				E	VO1 closed
2:59				E	VO1 increase to demand value
3:00			"It seems (*unintelligible*) five minutes here."		

4:06		O	"Now the change is significant (*may be referring to V2*)... keep on going back and forth frequently (*referring to heater settings?*)		
4:35			"Still (*unintelligible*) we should (*unintelligible*)."		
4:46			"For reservoir one, four and a half... it seems (*unintelligible*)."	E	H1, H2 fine tuning (several times)

Comments: Once the subject detects the fault, his first instinct seems to be check his own valve configuration procedures, to ensure that he has applied them correctly, given the demand flowrates. He goes about compensating for the loss of volume in R2, but seems reluctant to consider that there might be a fault somewhere in the system. His detection is based on the mismatch between his expectations of the effects of his procedures, and the actual system behaviour. In attempting to diagnose the fault however, he seems inclined to consider only one aspect of this mismatch, namely that his procedure may have been applied incorrectly, not that the problem could have been with the system itself.

Post-hoc: When asked how he found the trial, the subject stated "I don't think anything was very special", seeming to indicate that he did not think anything was wrong with the system. "I found the initial set up incorrect because the input was not equal to the output, so there is a quite significant fluctuation in water level (*in R2*) which destroys my equilibrium state which I have set it for." He made a very concerted re-evaluation of his valve configuration to make sure that he hadn't made a mistake which led to the system's unusual behaviour. He apparently understood quite well the manner in which flows were split between the valves in each feedwater stream and realized that there was a mismatch between the input to R2 and the output. However, he seemed to be completely unable to form a hypothesis about the reasons for the symptoms he observed, stating "I don't understand why."

Trial: 94 (start-up only)
Fault: 2 minutes after start of trial, R2 begins to leak at a rate of 4 units/second (D1=4, D2=11)
Subject: ML
Interface: P&ID
Initial Conditions: System in steady state. VA=8, VA1=4, VA2=10, VB=8, VB1=4, VB2=10, H1=4, H2=4, V1=10, V2=10.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:13		O	"Seem to be losing a lot of water here (*R2*)... I'm not entirely sure why."		
0:14		O	"Ten, eleven, and four is fifteen, seven and a half..." (*subject is checking his valve settings to ensure that he has properly configured the system according to his procedures*)		
0:24				E	VA, VB fine tuning (*subject is making sure that they are each set at exactly seven and a half and so will supply exactly enough water to meet the total output demand rate*)
0:31				E	VO2 closed
0:32				F	"Better shut that (*VO2*) down or else it (*R2*) will blow up (*from being heated empty*)."
0:38				D	"We'll shut this (*likely referring to input to R1*) down altogether and see what happens."
0:43				E	VO1 closed
0:44				E	VO2 opened to 10
0:45		I	"Obviously something's gone wrong."		
0:47				E	VO2 decrease to 5
0:53				D	"Just trying to find out where it's gone wrong... presumably somebody's pipe is screwed."
0:58				E	H1 turned off
1:02				E	VO1 increase to 10
1:08				E	VO1 decrease to 4

1:10		O	"This (*R2*) is getting ten (*from VB2*) and ten (*from VA2*), almost full input and it's... still dropping." (*subject does not appear to consider that VA and VB are each set to 7.5, and therefore that 7.5 is the maximum flow available from each feedwater stream*)		
1:20				E	VO2 closed
1:22		I	"All right, so let's assume this one (*VB2*) doesn't work."		
1:23				E	VB2 closed (*note that since VB1 was already closed, this action puts PB in a failure condition*)
1:37		O	"Ten..." (*referring to VA2*)		
1:39				E	VA1 closed (*to divert more water to R2*)
1:42				E	VO1 closed (*because V1 is getting very low*)
1:47		O	"All ten... (*likely referring to VA2*) did I blow up or something?"		
1:51					**R1 heated empty** (*When VO1 was closed, the water in R2 drained completely before the flow through the valve dropped to zero*)

Comments: The subject detected the fault through the mismatch between his expectations, based on his rules for setting up the system, and the actual behaviour of the system. When the subject had detected the fault, his first action, similar to subject WL, was to attempt to verify that his valve configuration strategy had been applied correctly. However, unlike WL, once he confirms that his procedures have been implemented as usual, he is quick to conclude that something has gone wrong with the system itself. He deliberately experiments with the system components to attempt to discover what is wrong, however he reaches an incorrect conclusion, postulating that VB2 is malfunctioning. He thus closes VB2, which, if the trial had not ended due to R1 being heated empty, would have caused PB to fail, since VB1 was already closed. He offers no other possible explanations for the unusual behaviour of the system.

Post-hoc: The subject seemed very frustrated after the trial. When asked what happened he simply stated that R2 had blown up because the water ran out.

When asked if he had any idea why this might have occurred, his response was: "No, no, can I go now?"

TRIAL #97

Summary: routine fault (heater), baseline trial for transfer trial #223

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: IS
Interface: EID
Initial Conditions: Adjusting H2 and fine tuning mass when fault occurred. V01 and V02 are set to demands, VA1 and VA2 are set to half, VB2 is set to full, VB1 is off. H1 is set to full and H2 is set to half. Both reservoirs are half full. The system is almost at steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	In the time between the fault and detection IS is fine tuning the valves and H2. He intermittently sets the mouse pointer on H1 but does not click. The third time he looks at H1 he remarks:				
1:19	"very odd"				
1:28		I	"it quite simply refuses to go up anymore" *(H1)*	E	H1 increase
1:32		O	"there we are" *sees that heat transfer is increasing*		
1:50				E	H2 increase
1:58				E	H1 decrease
2:04				E	H2 decrease
2:08		I	"heaters are very sluggish. I don't quite understand"		
2:13				E	*Subject is tweaking both heaters*
2:36		I	"Apparently the heater settings are not giving me a clear indication of what is going on"		
2:46				E	H2 decrease
2:50			"I think it is for this one too" *thinks that H2 has a problem also (?).*		
2:52				E	H1 increase
2:59					"just wait and see" *(he waits)*
3:05				E	*The subject fine tunes H1*
3:14					*The subject appears to have achieved steady state*
4:03		I	"obviously there's something wrong with H1, nothing drastic, just odd. H2 and R2 seem OK"		
4:22				E	*fine tunes H2*

4:40		I	"Getting the impression that the energy flow is giving me the wrong #'s" (*points to R1 energy balance*) "keeping an eye on that"	E	*fine tunes heaters*
6:21		I	"It's funny but I thought that I drastically over-compensated...if the bar is not giving me the proper reading" *Possibly referring to heat transfer rate bar on H1.*		

Comments: After detecting the fault, the subject increased and decreased heater values for both H1 and H2. This appeared to confirm his suspicions that H1 was not functioning properly. After doing this he concluded that "obviously there's something wrong with H1. H2 and R2 seem OK".

Post-hoc: Everything was working perfectly except that he recognized that H1 was only working at about half but the energy flow graphics for R1 were working (when vertical line Ein = Eout). He diagnosed from the discrepancy between heater setting and flow and then compensated by trial and error.

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: AS
Interface: EID
Initial Conditions All input valves are open. Reservoirs are both a third to a half full. H1 is on full and H2 is at 50%. Output valves are open.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	For the minute and a half before the subject detects the fault he modifies the setting of H1 five times: dropping it to half, gradually increasing to full, then down to 8 and then back to full again. At 3:29 he says "System has reached steady state and I'm waiting for set points to change."				
3:50		I	"This heater (*H1*) doesn't seem to be working properly. I'm setting it to its maximum and it's still not going to the maximum."		
4:48		O	"Whoops, I'm starting to overshoot" (*on T1*)	E	*Fine tunes H1 and ends up setting it @ 8*
5:34				F	"I'm doing some fine adjustments now."
				E	H1 decrease
6:07			"The set points will change any minute now."		

Comments: He seemed to begin to recognize the problem with the heater about two minutes after the fault when the temperature is not going up. He then experimented with H1 for about a minute and a half. Then, at 3:50, he explicitly stated that something was wrong. The system was already in steady state so all he had to do is monitor and fine tune.

Post-hoc: "This fault was not as bad as the previous ones. It's just that the heater was a problem, when I set it to maximum it's not going to maximum, it's just going half way." I noticed it when "I moved it (*H1*) to max. and it didn't go to max." He said that he always started with H1 set to high and then he leveled the temperature off afterwards. Because of this procedure he "almost noticed it immediately when the temperature wasn't moving". When he noticed that it was not working the temperature was nearly into the goal range so he did not need to do much adjusting. He said that he would

have added more water if he still could not get the heat up. He knew that this would take longer but the extra water would retain more heat. NB: He appeared to be confusing temperature and energy. An increase in volume will result in an increase in energy in the system but not an increase in temperature.

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: AV
Interface: EID
Initial Conditions: VA1, VB2 fully open and VB1 partially open (similar configuration to TL). H1 full and H2 set to half. Output valves open and reservoirs have low volumes.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	The subject spends the time between the fault and detection fine tuning the components in a somewhat regular "circle". He does this by starting with R1 output valves, then going to the heater, input valves, R2 input valves, output valves, heater and so on. The first time he does this checking cycle is 19 seconds after the fault. He fine tunes the components including H1 which he clicks to verify that it is on the highest setting. This is the only time he clicks on H1 before detection. However, he does pause on H1 several times in the course of his fine tuning cycles. By about the third cycle he says:				
1:59	"I wonder why it takes so long to heat up?"				
2:04				E	H1 to half
2:07				E	*H1 Clicks many times to full*
2:14		I	"Whoa... Something is wrong with this one." *points to H1*		
2:18				E	*H1 quickly set to half then to 8*
2:20		I	"Why does it do that?...Probably something wrong with it (*H1*)."		
2:41				E	H1 to full
2:48				E	H1 to 8
2:50				E	VA1 increase
2:58				E	H1 to full
3:02				E	VA1 increase
3:05		I	"It seems to me that there are a lot of things going wrong with this one."		

3:11		O	"This one (*H1*) only came half way up. I haven't done something wrong, Jesus Christ."		
3:24				E	VA1 increase
3:44				D	"Put some water in."
3:44				E	V01 fine tune
4:00				E	V02 fine tune
4:30		O	"Of course, now that I build up so much water in there (*R2*)...	D	"...now open this up some (*V02*), OK I have it there (*no actions, he is only checking*)..."
4:35		O	"...Are we going to have enough water from both of the pumps, of course." *he seems to be checking for the condition that the demands are greater than the supply as happened in trial 95*		
5:15				E	VA2 decrease
5:16				E	H2 decrease
5:26		O	"Do we have enough water in here (*R2*) now? Enough."		
5:29					
5:55		I	"OOPS...That shouldn't happen"	E	H2 increase and fine tune "Don't cool down on me"
6:25				E	H1 increase
6:38		I	"Something wrong with this guy (*H1*)"		

Comments: He quickly set up the system before the fault. He then fine tuned the system. Since he began with H1 on full, he did not need to change it significantly after the fault. This was because, given the fault and the rate of flow through R1, the goal was already being satisfied with the heater on full (even though the heat transfer rate is half). Hence the subject only needed to fine tune the system following the fault; he did not need to compensate any more than executing a few small adjustments to H1 and the input and output valves. The subject appeared to diagnose the fault when he realized that the heat transfer rate would not increase anymore, even though the heater setting was at maximum.

Post-hoc: "H2 doesn't work. I noticed it immediately, after about 30 seconds. Since it didn't heat as fast. I didn't do anything since it was almost OK. I then added some water just in case you did the same thing to me as the other time." (He is referring to trial #95 where D1 + D2 was > 20). "Instead of

regulating temperature with the heater (*which he knew was broken*), I regulated it with the water."

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: TL
Interface: P&ID
Initial Conditions: H1 set to full and H2 set to 4. VA1, VA2 and VB1 on. 20 seconds after the fault TL sets H1 to about half (because T1 goal has been reached) and then gradually increases the setting to maximum for the next 40 seconds (because a heater setting of half cannot satisfy temperature goal T1).

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:59	"I'm getting all confused again"	I	"why is it getting so cool? (*points to H1*)		
1:05				E	VA2 increase and then decrease
1:28				E	H2 decrease
1:40			"Hellllooooo" (*apparently talking to VA1*)		
1:45				E	VA1 off
1:50				E	VA1 on
2:03		O	"Well I think that we've finally achieved something here, though I'm not sure what"		
2:09		I	"I'm confused about why it is so hard to heat up R1"		
2:21				E	VA1 increase
2:48		I	"this is so bizarre"		
2:52				E	VA1 decrease to 3
2:56				E	H1 from half to full and back
3:10				E	VA1 to 6
3:20		I	"Glad I put an extra quarter in the meter today, it looks like we're going to be a while."		
4:23		I	"cooling down again saving some (*unintelligible*)"		
4:41				E	*sets VA2 to 1 ;nothing to do with fault*
5:04				F	"filling up reservoirs just in case we get a situation like two trials ago where the output demand exceeded 20... which is (*more than*) the most water we can pump in at any one time" *He is referring to trial 95.*

5:32		I	"Seem to be barely holding our own here; it seems with a bit of a glitch on reservoir 1 heater or something"		
5:50				E	VA1 decrease then off
5:56				D	"let it (*R1*) warm up a bit" (*by stopping mass flow in*)
6:04				E	VA1 open
6:10				E	VA1 increase
6:16				E	*He opens VA1 almost full* "what the heck"
7:08				E	H2 fine tuning
7:12				E	VA2 increase

Comments: Trial and error was used to solve problem. It appeared as though he recognized that H1 was not producing heat as it should. This was evidenced by him increasing H1 gradually to maximum just after the fault. However, he spent the next several minutes apparently investigating the effects of flow on the temperature in reservoir 1. After this exercise he unconfidently diagnosed the problem. He then controlled the temperature in the reservoir by adjusting the input flow rate (VA1) for the rest of the trial.

Post-hoc: He didn't like the trial. Heater 1 didn't work. "You had to set the heater to a higher setting for a given amount of water coming in". He figured it out because "things got cold and I kept turning the heat up." He then played with the heater and it still got cold so he "reduced the input". He did this because "when there is less water coming in there is not as much to heat".

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: WL
Interface: P&ID
Initial Conditions: All valves are open. Reservoir volumes are about half. Both heaters are on (H1 full, H2 is at 3).

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	About one minute after the fault he begins to set H1 to half and to maximum several times before he detects that something is wrong.				
1:55		O	"This indicates that this (*H1*) should be at a higher level"	E	H1 to full then half again
2:00				F	"Should be 5 for the first one"
2:28				E	H1 to full
3:05		O	"It seems that 4 is appropriate for the second heater"	F	"but for the first one I'll try a higher temperature (*than he expects*)"
3:10				E	H1 from 10 to 6
3:43				E	H1 to full
4:01				E	tweaking H1 between 6,7,8,7
4:41				E	H1 to full
4:52				E	H1 to 6
5:28				E	H1 to full
5:37				E	H1 to 7
6:50				E	H1 full
6:56				E	H1 to 8

Comments: He appeared to control by the use of cues from the output flow rate. That is, he looked at the given demands (D1 and D2) and from this he knew at what values to set the heaters and input flow rates based on rules derived from experience. When he saw that the goal for T1 was not being satisfied, he changed the setting of H1 from maximum to half several times. From this experiment, he recognized that H1 no longer satisfied his rules. This was when the fault was detected. After using this method to detect the fault, he tweaked H1 several times until the temperature goal for R1 was satisfied. At no point does he try to understand the underlying reason for the fault (i.e., that H1 is broken), he merely devises a new rule, by trial and error,

which can be applied to H1. This was shown in his post-hoc discussion when he said that there was nothing wrong except that the heater setting was higher than he expected (the heater after the fault requires a setting of 8 instead of 5 in order to satisfy the demand for temperature). This only addresses how the heater should be set, it says little about the heater's ability to function. Presumably, if for all future trials the heater had the same problem, then this subject's rules for control would adapt and he would never know that the heater needed repair.

Post-hoc: "Nothing unusual, very easy" "Maybe one thing strange: heater setting is much higher than I expect. It should be 5 but is really 7 to 8".

Trial: 97 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: ML
Interface: P&ID
Initial Conditions: All valves open. Both reservoirs about half. Both heaters about half. Output valves open. System nearly at steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:59		O	*(Counting demands)* "2-4 so (*H1*) should be around 4 but it's getting cold so go figure"		
1:10		O	"let's check on #'s again" *he goes to second reservoir.*	E	H1 to full
		O	"This 10 + 2 is 12, 14, 16, that's 8 through each (*VA & VB*) 8, 8 (*verification*)" *He is taking the sum of the output demands and using them to determine his valve settings. He does this by dividing the demand pair sum by two and setting VA and VB each to this number thus providing the necessary throughput of water. He then looks at output demand D1 and sets both VA1 and VB1 (the input valves for R1) to the same value as D1. He then does the same for R2. In this way the input valves mirror the output demands.* *In order to control flow with this configuration the subject needs only to fine tune VA or VB and ignore the four secondary valves (since they have been pre-set to mirror the output demands). The problem with this method is that a change in VA, for example, affects both R1 and R2. Hence, if an increased flow is needed for R1 and VA is increased, then flow increases for both reservoirs. When this happens VB needs to be fine tuned to compensate etc.* *This method is very difficult to utilize if the secondary valves are not set perfectly or if something goes wrong with one of the system components.*		

1:29		O	"Ratio is ... half of this which is 2 and half of this which is 6" (*checking to see if ratios of valve settings for VA2, VB2 and VA1, VB1 to output demands are correct*) "2 into here, 2 into here, 6 into here, 6 into here" *He shows that ratios are correct for respective valves.*	E	H1 to 4
1:51		I	"What did they do with the temperature? Why isn't this temperature responding the way it always does?" *He notices that there are problems with temperature but he doesn't know what is causing it.*		
1:57				E	H1 to full
2:02			"I guess that this trial is a test"		
2:08				E	H2 fine tuned
2:10		O	"This tank seems to be OK" (*he checks R2*)		
2:13		O	"This one (*R1*) just the temperature is psycho."		
2:18		O	"Don't know what's been done to it but..."		
2:26				E	H1 off
2:30				E	H1 to 8
2:49		O	"And the (*unintelligible*) on 8 seems to be semi- suspended"		
2:52				E	H1 increase
2:59		I	"it's (*H1*) certainly much more responsive" *This is because of the incredibly low volumes he has at this point.*		
3:08				E	H1 decrease
3:22				E	H1 off then on
3:32		O	"wow, it seems like almost lightening fast the way that temperature is being affected there, like instantaneous" *Because he has very low volumes; he is referring to R1.*		
3:56		O I	"well, 8 (*setting of H1*) seems to be a happy place here which makes no sense whatsoever under past experience"		
4:02		O	"here (*R2*) a little over 4 and again everything seems to be happy there"		
4:14		I	"Water levels are more or less behaving as far as I can tell"	E	*Fine tuning output flows V01*

4:33			"it took me a while to reach steady state largely because of the damn temperature"		
4:37			"so I went into (*steady state*) at about 3.5 minutes so I'm looking for about 8.5 as long as I don't slip out of it in the meantime" *He is anticipating when tuning will occur.*		
4:54			"nothing like these troubles to make life exciting, I guess that's what we're getting into now. We've been through enough of the training, now we're into troubles."		
7:30			"whistle Dixie" *Whistles Dixie.*		

Comments: He never really knew what caused the problems he was having. Steady state was reached by trial and error. Like WL (see comments) he uses strict rules of thumb to bring the system to steady-state. When these rules are violated he experiments with the system until he finds new settings that allow him to achieve steady state. He does not attempt to understand the underlying cause of the problem, he only devises a new set of rules that work to help him to finish the trial.

Post-hoc: "I had to set heater to double normal". He did not talk about the heater in terms of function. He only described the problem in terms of heater settings and how the new settings violated his rules.

TRIAL #165

Summary: routine fault (reservoir leak)

Trial: 165
Fault: 9 minutes after the start of trial, R2 begins to leak at a rate of 4 units/second (D1=3, D2=9)
Subject: IS
Interface: EID
Initial Conditions: System in steady state. VA=10, VA1=3, VA2=0, VB=10, VB1=0, VB2=10, H1=3, H2=3, V1=70, V2=40.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
0:34			"OK, that's interesting..."		
0:38				E	VA2 increased
0:39		O	"The water level in reservoir two is dropping."		
0:43				E	VA1 increased
0:49				D	"Just trying to accommodate it (*i.e., compensate for the volume change in R2*)."
0:58				E	VA1 fine tuning
1:02				E	H2 fine tuning
1:15		O	"Can't tell if it's (*V2*) stopped falling or not... unfortunately."		
1:18				E	H1 fine tuning
1:22		O	"I think it (*V2*) has (*stopped falling*)."		
1:35		O	"OK, so the water level started falling in reservoir two,"	D	"so I simply increased input,"
1:37				F	"using VA2 from the other reservoir." (*i.e., he diverted water from feedwater stream 1*).
1:50		O	"Ooo, it's (*V2*) still dropping a little bit."		
1:52				E	VA2 increased
2:00				E	VA2 increased
2:18			"OK, luckily reservoir one is a bit more forgiving."		
2:28		O	"OK, there, it's (*V2*) rising, so that should be fine..."		
2:38				E	VA1 fine tuning
2:51			"Much better."		
3:07				E	H2 fine tuning
3:32					**shutdown begins**

Comments: The subject quickly detects the fault and compensates for it efficiently. However, he does not attempt a diagnosis. In the post hoc interview, he

revealed that he thought the system's behaviour was due to an incorrect reading on one of the gauges. He does not seem to consider the possibility of a physical problem with the system.

Post-hoc: "It was either the input valve FB2 (*i.e., the flowmeter FB2*) was giving a false reading or the output (*FO2*) was giving a false reading. The level of reservoir two was dropping even though input (*to R2*) matched output (*from R2*), so all I did to correct it was take water from the top system with VA2 and just increased it."

Trial: 165
Fault: 9 minutes after the start of trial, R2 begins to leak at a rate of 4 units/second (D1=3, D2=9)
Subject: AS
Interface: EID
Initial Conditions: System in steady state. VA=6, VA1=2, VA2=8, VB=7, VB1=2, VB2=7, H1=3, H2=3, V1=40, V2=45.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:34	"Oooh, it happened again."				
1:35				E	VO2 closed
1:40		I	"There is a leak somewhere."		
1:42				E	VA2 increased to 10
1:44				E	VA increased to 10
1:55				E	VA decreased to 8
1:58				E	VO2 increased to 8
2:17				E	VO2 decreased
2:18				E	H2 increased
2:21				F	"I'm increasing the flowrate from VA2 to the reservoir (*R2*)... to keep the net flowrate (*into R2*) non-zero, or to prevent it from going to negative... just to retain the water in the system."
2:55		O	"OK, this (*R2*) has almost reached steady-state again." (*this is false - VO2 is still set at a value slightly less than the demand value*)		
3:00		O	"And it looks like the amount of water in reservoir two is holding... so I'm OK."		
3:40				E	VA1 fine tuning
3:45				E	H1 fine tuning (several times)
7:56				E	VO2 increased to demand value (*VO2 had not been set to demand for a long time because of the subject mistakenly setting VO2 too low.*)
8:36				E	VO2, H1 fine tuning
10:19				E	H1 increased to 6

10:26		O	"OK, for some reason the setpoint (*T1*) in reservoir number one is dropping..."	F	"...that's why I'm increasing the heater (*H1*) temperature to compensate for it."
10:33				E	H1 decreased to 3
10:50			"Oh, come on..." (*he is close to exceeding the goal region for T1*)		
11:45		O	"Woops, damn, it's overheating again (*R1*)... sorry."		
11:46				E	H1 fine tuning
13:36					**shutdown begins**

Comments: The subject seemed to recognize the system's behaviour and very quickly guessed that there was a leak "somewhere." He compensated for the fault efficiently by opening VA and VA2, although due to his fully coupled valve configuration, this affected R1 in addition to R2, causing him to spend an equal amount of effort stabilizing R1.

AS took a long time to complete the trial because he thought that he had set VO2 to demand, but in fact had set VO2 just below the goal. He did not notice this error for several minutes, hence, his total time was greatly increased.

Perhaps the most interesting part of this trial was the post hoc interview (see below) where it was revealed that AS had a pair of major incorrect assumptions about the system, and that his recollections of his own previous performance were far from perfect.

Post-hoc: Subject stated: "Looks like there's a leak in reservoir two." When asked how he knew, he said that he had achieved a stable volume in R2 with equal input and output, when suddenly the volume started decreasing. To compensate, he increased the input flowrate to R2 to compensate for the loss. When asked about the fact that he operated the system for an extended period with the output flowrate from R2 set at less than the demand value, he stated that he thought that he only had to meet the temperature goals, a serious misconception. Presumably he meant this only in the context of this trial, or fault trials, and not as a general rule, but this is not clear from his statements.

AS heated reservoir 2 empty during the shutdown phase of this trial and subsequently made a very interesting comment regarding his shutdown strategy. He stated that he had previously thought that in order to avoid heating a reservoir when empty, he had only to ensure that the bar indicating temperature had dropped below the green goal region, another serious misconception. He then stated that on this trial, he waited until the temperatures went "all the way down" (it's unclear if he meant to 10 degrees), before turning off the input flows to the reservoirs, yet reservoir 2 still failed due to being heated empty. Because AS heated reservoirs empty fairly often, the experimenter continued the discussion, asking him if it was usually reservoir 2 that he heated empty. He replied that he had never heated reservoir 1 empty. Upon checking, it was found that this was false, that AS had heated reservoir 1 empty a total of 5 times during the experiment until that point, the most recent being only two trials earlier!

Trial: 165
Fault: 9 minutes after the start of trial, R2 begins to leak at a rate of 4 units/second (D1=3, D2=9)
Subject: AV
Interface: EID
Initial Conditions: Mass and energy output in goal regions. VA=0, VA1=0, VA2=0, VB=10, VB1=0, VB2=9, H1=0, H2=3, V1=50, V2=90.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	(note that subject is employing anticipatory shutdown strategy - R1 is draining at the demand rate - H1 and all input valves to R1 have been shut off)				
0:20				E	PB, H2 shut off (*subject is now implementing shutdown strategy on R2*)
1:00		O	"It's a little bit too fast (*referring to rate at which V2 is dropping*)... what's wrong?"		
1:18			"Shit... oh shit!" (*subject realizes that R2 will likely drain before the setpoints change to zero*)		
1:22				E	PB turned on
1:23				E	H2 increased to 5
1:40			"Aww, fuck it!" (*subject becomes frustrated and gives up, refusing to try to restabilize the system*)		
1:49			(*to experimenter*) "You guys made a dirty trick on me again."		
2:04			"The second pump (*PB*)... the output (*from R2*) was more than... I had it (*VO2*) about eight and it (*the output flowrate*) was more like twelve. So it screwed up my counting (*i.e., the reservoir would have drained before the time at which he had anticipated the setpoints to change to zero*). It (*R2*) was outputting faster..."		
2:15			"Well, I had it (*VO2*) at eight right, but the rate of descent (*of V2*) was more like twelve or thirteen..." (*This observation is correct because the demand is 8 and the leak is 4, hence, the total amount of water leaving R2 is 12.*)		
2:21					**R1 heated empty**

Comments: This trial represents a unique interaction between AV's shutdown strategy and the unexpected behaviour of the system. The subject detected the fault through the fact that V2 was dropping faster than he anticipated, which he realized would cause R2 to drain before the setpoints changed to zero. This emphasizes how well attuned AV was to the rate at which the volume level was changing during his shutdown procedure. Since he had already shut off the input to R2, he could not have detected the problem through a mismatch between the input and output flowrates. He was able to tell, simply by watching V2, that it was draining at "twelve or thirteen." (R2 was, in fact, draining at a rate of 13 units/second). He subsequently made a token attempt to compensate, but, likely realizing that this would mean spending another five minutes re-achieving steady state, decided to give up instead, letting R2 drain completely. Had he begun his shutdown strategy earlier, the fault would likely have been inconsequential, and he may not even have noticed it at all. In any case, the subject makes no attempt at a diagnosis, although he was clearly aware of the relevant symptoms.

Post-hoc: (*continued from last statement during trial*) ...so it screwed up my timing." When asked what he did to try to fix the problem he replied "Nothing!" When asked why, he said "Because I got pissed off!"

Trial: 165
Fault: 9 minutes after start of trial, R2 begins to leak at a rate of 4 units/second. (D1=8, D2=7 change to D1=3, D2=9).
Subject: TL
Interface: P&ID
Initial Conditions: Satisfying mass and energy goals. FWS A off and VB=10, VB1=0, VB2=9. H1=off, H2=3. V1=40% and draining (subject is anticipating shutdown), V2=60%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:15	"Oh, what's happening now?"				
:20		I	"It (*R2*) seems to be draining." *Subject seems to be implying that the reservoir is draining too fast. Given his subsequent actions, i.e., adding more water to R2, this inference appears warranted.*		
:23				E	VB2 increase to 10
:33				E	VA1 off
:34				E	PA on (*Subject is configuring system so that PA can supply water to R2.*)
:35				E	VA2 to 2
:41				E	VA2 to 5
1:00				E	H2 to 4
1:03				E	H2 to 5
1:06				E	PB off, PA off (*Reservoirs are now full enough to satisfy demands for the rest of the trial.*)
1:11				E	H2 off
1:26				E	PB on (*to add water to cool residual heat transfer from H2*)
1:33				E	PB off
1:49				E	PB on
1:54					*System shutdown begins.*
1:55			*Subject lets out a large sigh of relief. If demand pairs did not change soon he would have had trouble maintaining steady state with such a low volume.*		

1:59		I	"That was close, the input valves went a little wonky there. Enough water in the reservoir to recover (*from the problem*)."		
2:30					**Reservoir 2 heated empty**

Comments: TL quickly detected the fault and compensated by adding more water to R2. Because he already had a high volume in R2, he did not need to compensate very much since he surmised that demands would change soon.

Post-hoc: "This valve (*points to PB2*) started going off, I think." He has no idea what the fault was. "Reservoir 2 started draining, so I think VB2 probably malfunctioned or something." Since it was near the end of the trial and he had enough water in the reservoirs, TL continued with what he needed to do to anticipate shutdown. With respect to R2 being heated empty, he said that it normally takes about a minute for the heating coils to completely cool. In this trial, he said that he forgot to give the heating coils enough time to cool off because of the speed at which the reservoir was draining (this was exacerbated by the leak in R2).

Trial: 165
Fault: 9 minutes after start of trial, R2 begins to leak at a rate of 4 units/second. (D1=8, D2=7 change to D1=3, D2=9).
Subject: WL
Interface: P&ID
Initial Conditions: Appears to be in steady state. VA=10, VA1=2, VA2=4 and VB=10, VB1=2, VB2=4. H1=3, H2=3. V1=30%, V2=50%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	30-35 seconds after the fault subject incrementally increases VB2 to 10 and adjusts H2.				
3:00					*System shutdown begins.*

Comments: Subject does not comment during the trial. He does not appear to recognize the fault. However, he unknowingly compensates for the fault.

Post-hoc: When asked how the trial went, the subject responded: "It's harder to maintain temperature for the first one (*R1*) than for the second one (*R2*)". This indicated that he did not even detect the fault.

Trial: 165
Fault: 9 minutes after start of trial, R2 begins to leak at a rate of 4 units/second. (D1=8, D2=7 change to D1=3, D2=9).
Subject: ML
Interface: P&ID
Initial Conditions: System appears to be in steady state. VA=6, VA1=3, VA2=9 and VB=6, VB1=3, VB2=9. H1=3, H2=3. V1=10%, V2=25%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:18	"Oh,..."	I	"Something blew up."		
1:25				E	VO2 closed.
1:45			*(unintelligible comment)*		
1:50				E	VO2 open to 9.
2:11			"Well, why is it doing that?" *Subject appears to try to reset R2 water level but it keeps dropping because of the leak.*		
2:16				E	VO2 close
2:18				E	VB2 to 10
2:21				E	VA2 to 10
2:33				E	VO2 open to 9
2:44				E	VB1 decrease
2:45				E	VA1 decrease
2:50				E	H1 decrease
2:51				E	VA increase
2:54				E	VB increase
2:58				E	VO2 close
3:01				E	VA increase
3:04				E	VB increase
					Subject is increasing input and reconfiguring the system. Because of his "ratio" valve configuration where the FWSs are coupled, he must also reconfigure FWS A to compensate for changes made on FWS B.
3:06				E	H1 off

3:08		I	"Obviously, something is going wrong, I may have to deal with it. Joy, joy, joy." *Subject is sarcastically stating that he is happy about having to compensate for the fault.*		
3:19				E	VA to 10
3:20				E	VB to 10
3:23				E	VO2 to 3
3:41				E	H1 fine tune
3:48				E	VB decrease to 9
3:52				E	VA decrease to 9
3:56				E	VA1 increase
3:59				E	VB1 increase
					Again, it should be noted that the subject must reconfigure both FWSs to compensate for the fault in R2. If he decoupled the FWSs, he would only have to worry about one valve setting on FWS B.
4:14			"I have no idea what to do. (*unintelligible*) There's nothing to tell me what's wrong and to what extent."		
4:45			"Seems to be holding, sort of, now." *Subject appears to have stabilized the system.*		
5:15				E	H1 fine tune
5:17				E	H2 fine tune
5:37				E	H1 fine tune
5:39				E	H2 fine tune
5:54		O	"Looks like it's close to temperature (*goal on T2*). This one (*points to T1*) looks like it's still...Oh, it's (*R1 volume*) dropping. Give me a break."		
6:04				E	VB increase
6:10				D	"So I need to put more water in (*to R2*)."
6:12				E	VA1 increase
6:22				E	H1 decrease
6:30				E	VA, VB fine tune
6:33				F	"(*unintelligible*) let's try 2.5, 2.5."

6:35				E	VA1 to 2.5, VB1 to 2.5
6:55				E	H1 decrease
7:37				E	H1 increase to 8
7:42				E	H1 decrease to 4
7:53		I	"Seems to be sort of stable on water level just now, whatever was wrong with it." (*It's not clear whether he is referring to R1 or R2.*)		
8:01		I	"It's temperature I'm having a problem with. It seems to be OK, it's been steady for a while (*points to T2*)."		
8:11		I	"This one (*T1*) isn't quite so happy." *There is nothing wrong with T1, subject is just having trouble with it because, due to his coupled FWSs, any modification to the valve configuration he makes to compensate for the leak in R2 affects R1 and, hence, T1.*		
8:30				D	"Still have a bit more water flooding into it, so I'm just (*unintelligible*) that a little."
8:33				E	H1 fine tune
8:34		O	"Yeah, I just saw some (*unintelligible*)."		
8:46				E	H1 increase
8:47				D	"(*unintelligible*) this a little bit 'cause it just dropped."
8:48				E	H1 decrease
				F	"Let's try that (*setting of H1*) somewhere around there."
8:58		I	"Oh, now it is acting out of control." (*Possibly referring to T1.*)		
9:02				E	VA, VB fine tune
9:13		I	"All of a sudden they're (*reservoirs*) both filling up really quickly, like really realistic." *The subject sarcastically implies that the simulation is unrealistic with respect to the reservoirs appearing to quickly increase all of a sudden. It is likely that he perceives this because he has been focusing on temperature for the past two minutes and ignoring volume*		
9:27		O	"This one (*points to R2*) is dropping again."		

9:29				E	VA1 decrease, VB1 decrease (*these actions have the net effect of increasing flow to R2 at the expense of flow to R1.*)
10:20		O	"39 and 26" *Subject is noting the levels of R2 and R1 respectively.*		
10:33				E	H1 fine tune
11:15				E	H1 decrease
11:19		I	"So 3.5 is too high (*H1*) for that one."		
11:32			"God. Stupid."	E	H1 fine tune *System shutdown begins.*

Comments: Subject detected (and, in the post-hoc discussion said that he had diagnosed) the fault, but was unable compensate effectively for it. Because he unnecessarily coupled both feedwater streams, and modified VA and VB to control flow, he was constantly compensating with H1 for changes made to compensate for the leak in R2. This happened because any change made in the flowrate through either VA or VB affected both reservoirs.

Post-hoc: Subject said that the trial was much, much harder than usual. He stated that there was a leak in R2 and that it affected the whole system since any change he made to control for the fault affected everything else. This happened due to his coupled FWS configuration.

He said that he did not care about reservoir levels, he mainly focused on the heaters. He liked low reservoir levels but did not keep them at any particular level; just wherever the levels happened to be when he finished configuring the input valves. This was done because it kept the system more responsive. He explained that this is intuitive because the more water you have, the longer it takes to heat.

TRIAL #183

Summary: routine fault (heater)

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: IS
Interface: EID
Initial Conditions: System is at steady state when the fault happens. VA=10, VA1=9, VA2=0 and VB=10, VB1=0, VB2=6. H1=9, H2=2. V1=45%, V2=35%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:21				E	*Just after the fault, subject increases H2.*
:25	"Well that's interesting."	I	"There seems to be something odd with heater 2."	E	H1 decrease
:37				E	H2 increase
:40				E	H1 increase
:48				E	H2 decrease
				F	"OK turn that (*H2*) down a little."
:50		I	"OK, the heater in reservoir 2, the setting has to be twice what you already want it to be. Easily manageable."		
:52				E	H1 fine tune
1:03				E	H2 fine tune several times
1:35		I	"There's absolutely nothing wrong with reservoir 1. Everything seems stable."		
				E	*Subject spends remainder of trial fine tuning components as necessary.*
1:41		I	"Reservoir 2 seems fine, with the exception of the discrepancy between the setting and the actual heat input, you could call it."		
2:05			"OK, I'm comfortable with this."		
4:10					*System shutdown begins.*

Comments: Subject quickly detects, compensates and diagnoses the fault. He remarks that the fault is "easily manageable".

Post-hoc: "The only, it wasn't really a problem, but the setting for heater 2 was double the actual input (*input of heat to the reservoir*) for H2 was." He noticed the fault when "H2 started misbehaving". "I had problems.

Usually I ignore the heater while I'm readjusting the water input and output (*when demand pairs change*) but I noticed that the temperature just wasn't behaving as it normally would. So I looked up and I realized that the settings were wrong (*i.e., where he had the H2 set*)."

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: AS
Interface: EID
Initial Conditions: VA=7, VA1=7, VA2=4 and VB=7, VB1=10, VB2=5.5. H1=7, H2=3. V1=45%, V2=45%.

Time after fault (min:sec)	**Detection** Activation		**Diagnosis** [O]bservation [I]dentification		**Compensation** [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	The demand setpoints change at almost the same time as the fault. At :37 seconds after the fault the subject states "OK flowrate is stabilized again, I will begin working on temperature now". When reconfiguring the system for the new demand pairs, he has stabilized mass first and will now stabilize energy. At 1:12 after the fault he states that "system has reached steady state again, waiting for the setpoints to change".				
1:40		I	"It looks like there is a slight malfunction on heater 2. The temperature (*he points to the heat transfer rate*) never meets the setpoint (*i.e., where the heater is set to*). It's almost like half what I set it to. But since the temperature variation in reservoir two is not great (*circles energy graphic on R2*) it doesn't really affect me at all." *Since temperature demands are not high, the subject does not have to worry about being able to compensate with his broken heater.*		
1:48					*System shutdown begins.*

Comments: Subject appears to unknowingly compensate for the fault. Once the system is in steady state he notices that the heat transfer rate is half of the setting for H2 and correctly diagnoses that H2 is broken, since its output is only half of what it is set to.

Post-hoc: "There is something wrong with heater 2. What happens is the temperature doesn't actually arrive at the point, at the adjust point; it's lower than what I

adjust." He said that since temperature demands were low, the fault did not "affect much". He explained that he compensated by moving "the marker" to double the setting that he wanted on H2.

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: AV
Interface: EID
Initial Conditions: VA=10, VA1=9, VA2=0 and VB=10, VB1=0, VB2=8. H1=9, H2@3. V1=100%, V2=80% and rising.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:01		I	*Subject was not focusing on temperature when the fault happened. The fault did not appear to affect his ability to keep R2 water at the goal temperature (due to the reservoir's large volume and the relatively small decrease in the output of H2 (1.5)). When R2 was almost full, he turned off PB and H2 because he had enough heated water in R2 to last until shutdown. Just after executing these actions, he recognized, almost as an afterthought, that the heat transfer rate on H2 was less than its setting.* "Something happened to the heater while I wasn't watching."		
1:12				E	H2 turned on and set to 2
1:15				E	H2 off
1:40				F	"Turn this guy off, I think that's enough time (*to heat the water*)."
				E	H1 off
1:49				E	PA off
				E	*Subject proceeds to anticipate the system shutdown by closing all input valves and waiting.*
3:30					*System shutdown begins.*

Comments: Just after the fault the subject was mumbling his time calculations for anticipating shutdown. He then turned PB and H2 off because he calculated that he had enough water in R2 for shutdown. Hence, he nearly avoided the fault. However, as the mouse pointer hovered over H2, about to shut it off, the subject detected the fault. He did not need to compensate for the fault because R2 had already been heated to goal temperature.

Post-hoc: AV's first comment was: "I think at some point the second heater got halved, but I wasn't looking at that moment." This was a remarkable observation considering he motioned to turn H2 off just as the fault happened.

The subject insisted that there was a connection between the fault and the videotaping of the trial. There was not: faults also occurred on days when there was no videotaping.

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: TL
Interface: P&ID
Initial Conditions: VA=10, VA1=9, VA2=0 and VB=10, VB1=0, VB2=6. H1=9, H2=2. V1=65%, V2=55%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	31 seconds after the fault occurs, the subject states "Need to heat up reservoir 2 a little bit". *The subject recognizes the need for more energy to be added to R2 but does not appear to recognize that something is wrong. He slowly increases the H2 setting and then remarks* "things are getting a little cool in reservoir 2, but I trust that it *(points to T2)* is still within the range *(goal)* though by a hair's breadth". *Over the next 2 minutes he begins to anticipate shutdown by turning off PA and PB, H1 and H2, and all the input valves. When the demand pairs still have not changed and the reservoirs are almost empty, he realizes that he must start all over again and begins to reconfigure the system. He first stabilizes volume and then begins to work on temperature. He subsequently modifies H2 several times before stating:*				
5:59	"Ummm, what's happening here?" *Points to H2.*			E	H2 increase to 5
6:25				E	H1 fine tune
6:30				E	H1 fine tune
6:42				E	H2 decrease to 4
6:56				E	H1 fine tune
7:20			*(Subject whistles as he makes adjustments.)*	E	H2 decrease to 3
7:30				E	H1 fine tune
8:24				E	H2 fine tune
8:28				E	H2 increase to 4

8:50				E	H1 fine tune
9:00				E	H2 fine tune
9:30		I	"Not taking any chances this time." *He is indicating that he will not try to anticipate shut down again.* "The temperature went down again in reservoir 2 about 13:40 (*6:10 after the fault, when he began to reconfigure the system after failing to anticipate shutdown*). I'll take that as the steady state time."		
9:38				D	*System shutdown begins.* "Oh, guess I was wrong (*about when shutdown would happen*). Do I have a minute in each of these (*reservoirs*)? I'll just let it (*the reservoir*) fill a little longer; at least a minute of draining time." *Subject normally allows one minute for the heaters to cool before he completely empties the reservoirs.*
10:53			"I just got confused about temperature. I didn't know where it was at some points (*in the trial*)."		

Comments: TL unknowingly compensated for the fault by slowly increasing the setting of H2. He eventually increased H2 to a point that he realized that something may be wrong with temperature because the setting of H2 was slightly greater than he expected. He choose to ignore the possible problem because he wrongly assumed that this "problem" had little or no effect on his ability to complete the trial. However, the fault did cause the temperature of R2 to drop just below the goal region. Hence, the subject was not able to achieve steady state in this part of the trial and the demand pairs did not change to zero, indicating shutdown. By the time TL realized that he had not achieved steady state, he had almost completely shutdown the system. At this point, he realized that something must have gone wrong. He then had to completely reconfigure the system by turning on the pumps and heaters, and resetting the input valves. In this trial, TL only detected the fault (after a relatively long time), and he was not able to diagnose it.

Post-hoc: "Temperature was falling and it went right to the lower limits (*of the goal range*) and I couldn't tell if it went below or not but it did and I was assuming it didn't. So when the time came (*demand pairs changing to zero*

for shutdown) it didn't come. So I just filled up the tanks (*and started all over*)." "I think that the heater (*H2*) went a bit off. Usually, in my mind I know that for a certain input water level, the heater level should be around a certain place. You make up these rules of thumb. (*They were*) pretty good until today." The subject detected the fault because the heater setting did not match his rule-based expectations.

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: WL
Interface: P&ID
Initial Conditions: Satisfying mass and energy goals. VA=10, VA1=4, VA2=3 and VB=10, VB1=4, VB2=3. H1=10, H2=3. V1=45%, V2=80%.

Time after fault (min:sec)	**Detection** Activation		**Diagnosis** [O]bservation [I]dentification		**Compensation** [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
11:39					*System shutdown begins.*

Comments: Subject did not detect the fault. He did not appear to notice the fault because he had no expectation as to what the heater settings should be.

Post-hoc: When asked how the trial went, the subject replied: "Very, very well". He did not notice the fault. However, he did complete the trial much faster than he normally did.

Trial: 183
Fault: 7.5 minutes after start of trial, H2's heat transfer rate starts to drops exponentially to half of the setting. (D1=6, D2=3 change to D1=9, D2=6).
Subject: ML
Interface: P&ID
Initial Conditions: VA=8, VA1=9, VA2=6 and VB=8, VB1=9, VB2=6. H1=10, H2=2. V1=25, V2=15.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Subject modifies H2 by increasing it and decreasing it several times before he says:				
:46	"Come on."				
:48				E	VB fine tune
:53				E	H2 decrease to 2
1:12				E	VO2 fine tune
1:15				E	H2 increase to 5
1:30		I	"I don't understand this. Obviously, well not obviously, it looks like there is something wrong with this heater (*Points to H2*)."		
1:41		I	"This should be going bananas." *Subject might mean that, given this particular heater setting, temperature should be out of the goal area.*		
1:48				E	H2 decrease to 3
2:19		O	"Now its (*T2*) going down again."	E	H2 increase to 5 (*Since his heater setting of 3 is lower than the necessary setting of 4, the temperature of the water in R2 is dropping.*)
2:24				E	H2 increase to 8
2:31				E	H2 decrease to 4
3:05		I	"Looks like it's double (*i.e., the heater setting*)."		
3:30		I	"Looks like it's (*R2*) about double, it seems to be happy around (*a setting of*) 4. The heater would normally be at 2 for this output." (*Subject is remarking on the discrepancy between his current heater setting and what he would expect.*)		

5:40					*System shutdown begins.*

Comments: The subject detected the fault because of a disagreement between his rules for system operation and the settings required for H2 in this trial. This difference also helped him to diagnose the fault precisely (i.e., the setting of H2 had to be doubled).

Post-hoc: "This heater was out (*points to H2*). Usually, I'd be setting it at 2 for the output level, but I had to set it at 4." The subject accurately diagnosed the fault.

TRIAL #187

Summary: routine fault (valve), baseline trial for transfer trial #224

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: IS
Interface: EID
Initial Conditions: VA, VB set to maximum. VA1 set to 6, VB2 set to 8. H1 set to 6, H2 set to 3. V1 constant at about 70% and V2 constant at about 40%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	At 7:38 the demand pairs change and he makes appropriate adjustments to the system in about 20 seconds. The system appears to be in steady state when the fault occurs.				
:26		O	"Nothing too exciting, just..."		
				D	"...shutting pump B down..."
:29		I	"...because it's (*points to VB*) not behaving properly"	E	PB off, VB off, VB2 off
:38				E	VA2 increase
:40				F	"Redirect valve A2 to compensate"
:45		I	"No problem..."	D	"Turn that down a little."
:47		I	"Otherwise everything is pretty stable."	E	VA1 fine tune
1:04		I	"That's fine (*the system*) no problems."		
1:41				E	VA1 fine tune
3:12		I	"Everything is behaving perfectly normal."		
3:37				D	"Turning down heater one just a tad."
3:40				E	H1 decrease
4:52				D	"And time to shut down"
				E	*The subject proceeds to shut down the system in a similar manner to other non-fault trials.*

Comments: The subject quickly detected and diagnosed the problem. His cue that there was a problem was that no water was going into R1 since the level was

decreasing. This was confirmed by the flow meters for VB and VB1. He quickly compensated and then finished the trial normally.

Post-Hoc: Upon finishing the trial he stated that "it went fine, after the settings changed, pump B shut down and wasn't working so I just redirected the water through valve A2". He said that he eventually noticed this because "there was no water running through the valves". He concluded by stating that "it (*the trial*) was easy. You've thrown that one at me before".

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: AS
Interface: EID
Initial Conditions: Demand pairs changed at 6:55 (one minute before the fault). He has his valve ratios set up as he does on all trials. Reservoirs are about half full. H1 is at 8 and H1 is set to 2.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	One second before the fault AS says "I think that the flow rate has been stabilized."				
:09		O	"Now it's (*R1*) dropping, why?"	E	VA2 increase
:15				E	VA1 to maximum (from half)
:23				E	H1 decrease (*this helps to stop temperature from increasing due to the decreasing water level in R1*)
:25		O	"It's still dropping, interesting."	E	VA to maximum (from half)
:27				D	"try this" (*opening VA to full, he may think that there is a reservoir leak.*)
:35				E	H1 off
:38					**PB blows up.** *He pauses an unusually long time before calling the experimenter over.*

Comments: AS detected the fault right away because he had just achieved steady state flow and was focusing on flow rates. However he focused on the wrong feedwater stream because the fault affected R1 more than R2 due to the larger amount of water being contributed by PB.

Post-Hoc: The first comment that AS made was "I didn't notice that VB is broken". He points at VB and says that he should have noticed it. "Everything is open (*the valves*) and nothing was coming in. I should have switched off the pump (*PB*)." He said that he focused on the top feedwater stream because he noticed water levels dropping on both reservoirs. "R1 seemed to be decreasing faster than R2 so I focused on the top". He was correct in his observation. Since VB contributed more water to R1 than R2, the net effect of the broken valve was more noticeable on R1. Due to AS's "ratio"

strategy, a fault in one part of the feedwater stream can propagate throughout the whole system. Had he decoupled the feedwater streams, he would have had a better chance at diagnosing the fault.

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: AV
Interface: EID
Initial Conditions: Demand pairs changed at 5:50 (over 2 minutes before the fault). VA1 and VB2 set to D1 and D2 respectively (decoupled feedwater streams). Reservoirs 80% full. Temperature is at steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Just before the fault, AV turns off PB (presumably because D1+D2 was less than ten meaning that demand could be completely supplied by the top feedwater stream using PA). He did explain in other analyses that this was the strategy he used for anticipating shutdown.				

Comments: AV never noticed the fault because he turned off PB before the fault. Hence the broken valve VB had no effect on his trial completion.

Post-Hoc: None.

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: TL
Interface: P&ID
Initial Conditions: Demand pairs changed at 5:49 (over 2 minutes before the fault). VA1 and VA2 set to D1 and D2 respectively (decoupled feedwater streams). Reservoirs nearly full. Temperature is at steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	By 6:12 he has changed his configuration to using just the top feedwater stream. At this point he says "Five minutes worth of water in reservoir 2". *This means that there is enough water in R2 to satisfy demand until shut down. He can now ignore this reservoir and let it drain itself. He did explain in other analyses that this was the strategy he used for anticipating shut down. He sings to himself as he completes the trial.*				

Comments: Because of the system configuration that TL adopts, he never had a chance to see the effects of the fault (because PB is off). TL efficiently set up the reservoirs with high volumes because the demands were low for the end part of the trial. TL used a similar strategy as AV: first by simplifying to one feedwater stream whenever he saw that the sum of demands were less than 10 and secondly by keeping high reservoir volumes so that shut down could be anticipated. Using this method, the heaters could cool as demand was being satisfied by the fully heated reservoirs.

Post-Hoc: None.

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: WL
Interface: P&ID
Initial Conditions: Demand pairs change at 6:47 (one minute before the fault). VA1 and VB1 set to D1 and VA2 and VB2 set to D2. VA and VB are fully open. H1 is at 6 and H2 is at 1. R1 is 60% full and R2 is almost completely full. He has the system at steady state when the fault occurs.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:41					PB blows up

Comments: WL absolutely did not even detect the fault. It was surprising that he did not notice the level on R1 drop like IS did (their initial configurations were similar). Nevertheless, he has no idea why PB blew up.

Post-Hoc: When asked how the trial went WL replied "Normal".

Trial: 187
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: ML
Interface: P&ID
Initial Conditions: Demand pairs changed at 6:09 (two minutes before the fault). Valves are set using his usual "ratio" strategy. H1 is set to D1 and H2 is set to one third D2. Reservoir volumes are about 20%. System is at steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	He turns H1 off just before he verbalizes the observation that the reservoirs' volume is decreasing. This may be as a result of increasing temperature levels due to a decrease in reservoir water level.				
:36		O	"Oh, they're (*the reservoirs*) both going down." (*It appears that he noticed R1 level decreasing first but he did not say anything.*)		
:37					**PB blows up**

Comments: ML noticed that the volume in R1 was decreasing. Because his volumes were so low temperature rose quickly so he turned off H1 so that the system did not overheat. He moved the mouse pointer to VA when he realized that both reservoirs were affected by the loss of water, but by this time it was too late and PB blew up.

Post-Hoc: He deduced afterwards that it must have been a block in VB that was causing the problem. However, he had no idea during the trial.

TRIAL #201

Summary: non-routine fault (reservoir leak and increased input water temperature)

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: IS
Interface: EID
Initial Conditions: VA=10, VA1=6, VA2=0 and VB=10, VB1=0, VB2=10. H1=5, H2 set to about 5. V1=60% full and V2=25% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:12	"Right now..."	O	"I'm noticing that reservoir 1 is dropping"		
:17				D	"I'm jut going to increase input to reservoir 1."
:19				E	VA1 increase several times
:27		O	"It's (*R1*) dropping quite fast."		
:42				E	VA1 increase
:43		O	"OK it doesn't seem to be dropping anymore."		
:45		O	"Yup, it is."	E	VA1 increase
:50				E	H1 increase
:58				E	VA1 increase to 10
1:17		O	"OK it (*R1*) stopped dropping now, but the heater temperature dropped. We'll just have to wait for that to get back up to temperature."		
1:30			"The way this is behaving is hard to figure out."		
1:38		I	"These readings are getting good values." *He is referring to VA, VA1, and VA2.*		
1:51		I	"There, I've got the heater back up to normal - or the temperature setting back to within range for reservoir 1." *T1 is in the goal area.*	E	H1 increase
2:00		O	"Reservoir 1 is still dropping but not too much- its manageable."		
2:00	*(Second fault begins.)*				
2:15			"I think"	E	H1 fine tune
				E	VA1 increase (*setting was already at maximum, he appears to just be verifying the setting*)

2:30	"Now heater 2..."	O	"...the temperature in reservoir 2 is skyrocketing, I didn't even notice." (*Subject has detected the effects of the second fault.*)		
2:35				F	"Turn that down."
				E	H2 decrease (*Subject is compensating for the second fault.*)
2:41				F	"Turn that up."
				E	H1 increase
2:52				E	H2 almost off
3:00				E	H1 decrease
3:16				E	H1 decrease
3:28				E	VA2 decrease
3:32				E	H1 decrease
3:40				E	H1 fine tune
3:54				D	"OK, so now I'll look at this properly." *After compensating for the fault it appears that he will now attempt to diagnose it.*
4:00				E	H1 fine tune
4:07				E	VA2 fine tune
4:10				E	H1 fine tune
4:47				E	H2 fine tune repeatedly
4:52		I	"So input and output levels are behaving for the reservoir 2 system" (*referring to mass balance graphics*)	E	H1 fine tune
4:58		I	"It's reservoir 1, even though heater 2 decided to kick in a little bit and now it doesn't need to be set nearly as high as normal."		
5:15		I	"I think I've got it (*H2*) fairly under control."	E	H2 fine tune
5:25		I	"H1...I think I have it pretty much stabilized."	E	H2 fine tune
5:39		O	"The level of reservoir 1 is still dropping, but very, very slowly."		
5:50			"So not too concerned."		
6:00			"Just wondering now at what point I reached stable settings again, I wasn't paying attention at the time so...."		
6:51				E	H1 fine tune
7:35			"Things are pretty stable now, no surprises."		

7:42			*Demand pairs change*		
7:58		O	"And settings have changed."		
8:02				E	*S fine tunes input and output valves and turns VA2 off to satisfy new demands.*
8:25				F	"Now should probably kick in a little bit from valve 2."
8:28				E	VB1 increase
8:44				E	H1 fine tune
8:52				E	H1 fine tune
9:11				E	H1 fine tune
9:28				E	Input valves fine tune
9:44				E	VB1 off
9:50				E	VB2 fine tune
10:06		I	"OK that seems about right." (*The subject appears to have the system stable. After this statement he moves the mouse pointer to H2 but never adjusts it.*)		
12:30		O	"Not much can be said. It's within limits."		
13:06			"Aaaah....I can't figure out what could have gone wrong with R1, why it would require much more heat and water input than necessary." (*The subject has to heat 4 units of water being lost to the leak plus 6 units throughput minus the 6 degrees added by the second fault, this results in the need for a higher compensation for R1.*)		

Comments: IS detected that something is wrong with flow on R1 and with temperature on both reservoirs. He spent most of the trial compensating and tried at times to diagnose (when he was not concentrating on compensating), but he never got very far.

Post-hoc: "It went severely wrong." "Reservoir 1 sprung a leak." From this comment it was clear that the subject knew what the fault was, yet he never verbalized it. "Also, there was something wrong with the heater on R1 because I had to set it at double what it is normally set at. While that was going on reservoir 2's heater decided that it was more powerful than it normally is." At this point he noticed the second fault. The reservoir leak

was noticed because "it started dropping really fast". He normally would not have noticed this but since he was fine tuning flow on reservoir 1, he noticed it.

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: AS
Interface: EID
Initial Conditions: System is in steady state when the fault occurs. VA=8, VA1=4, VA2=10 and VB=9, VB1=5, VB2=10. H1=5 and H2=4. Reservoirs are both about half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:33	"Oops, damn."		"It's (*Duress II*) playing a joke on me again."	E	VO1 closed, VA1 to 10
1:42		I	"Somewhere, somehow, reservoir 1 is leaking."		
1:49			"Geez, (*the fault*) almost caught me off guard."		
1:55				F	"I'm shutting down the output valve on reservoir 1 so that I can stop back more water."
2:00	*(Second fault begins.)*				
2:03				E	VA full
2:06				F	"I think I'll boost it (*VA*) a bit more."
2:19				E	VO2 decrease
2:26				E	H2 decrease several times to 1
2:49				F	"I'm going to turn VB1 on as well so that I can fill reservoir 1 faster."
2:53				E	VB1 to full
3:04			"You guys are good at this (*making faults for trials*), you caught me off guard."	E	H2 increase to 4.5
3:10				D	"OK I'll try it (*opening VO1*) again."
3:12			*(Apparently because of the fault, AS has abandoned his ratio rules for input valve configuration.)*	E	VO1 increase
3:30				E	H1 to full
3:33				E	H2 decrease
3:46		O	"Now the water level in tank #2 is dropping, damn." (*this is not an effect of the fault*)		
3:55				E	VO1 fine tune

4:00				F	"Let's see how much I can give it to you." (*The subject wants to try to see if he can divert some water to R2 from FWS A*)
4:04				E	VA1 decrease to 8
4:07				E	H1 decrease
4:15				E	H1 decrease
4:16				E	VA1 decrease and fine tune
4:36				E	H2 increase, H1 increase
4:41		O	"Oops, too much (*water*). Come on you can do it man (*hoping that his modifications work*)."	E	VA1 increase
4:50				E	VB to full
4:52				E	VB1 decrease
5:00				E	H2 decrease
5:15				E	H2 increase then decrease several times (*he is jumping the setting up and down every few seconds*)
5:30				E	H1 to full
5:49				E	H2 increase then decrease twice
6:00		O	"OK system is reaching steady state again, I hope."	E	H1 decrease to 5
6:12				E	H1, H2 fine tune several times for next 80 seconds.
7:41		O	"This one (*H2*) is overshooting."	E	H2 decrease
7:58				E	VO2 fine tune; H1, H2 fine tune
8:26				E	H2 off
8:33				E	H1 to full
8:35				E	H2 increase several times
8:50			(*The subject fine tunes H1 and H2 constantly through to the end of the trial. He fine tunes the output valves occasionally*)	E	H1 decrease several times
10:51		O	"OK, it's (*demand pairs*) finally changed."	E	*The subject adjusts output valves to new demands.*
10:57				D	"I'll drop the overall flow." (*The subject does this because new demands are slightly lower*)
11:00				E	H2, VA, VA1 decrease
11:05				D	"And I'll drop the overall flowrate."
11:09				E	VA decrease
11:20				E	H1 decrease
11:25				E	VA decrease then increase

11:35		I	"Looks like the tank is still leaking: the problem doesn't go away." (*Some subjects suspect that the fault may disappear when demand pairs change*)		
11:40				E	VA2 decrease
11:50				E	H1 increase
11:55				E	VA2 decrease
12:00			*The subject is constantly fine tuning H1 and H2.*	E	H1 to full
12:36				E	H2 increase, H1 decrease
13:00		I	"OK, the system has reached steady state again, I guess. I'm waiting for the setpoints to change to zero now."		
13:11		I	"It's (*H1*) dropping too low."	E	H1 increase
13:25		O	"It's (*T1*) coming back up again, I'm referring to the setpoint (*points to T1 goal region*)."		
13:45			*The subject constantly fine tuning H1 and H2.*		
15:35		O	"It's overshooting again (*referring to T1*)."	E	H1 decrease
15:50				E	H1 fine tune
16:25			"I am constantly adjusting the temperature for reservoir 1 because the input flow rate is larger than the output. This means that there is a net flow of cooling water flowing into the reservoir. That's why the temperature would always be dropping." (*This is not true: once the heater is set to compensate for the extra water inflow, no more tuning needs to be done. The subject does not recognize this.*)		
17:03				E	H1 decrease
17:10				D	"I have to find the right temperature gradient just to maintain the heat." (*The subject is trying to figure out what setting H1 should be at to stabilize temperature.*)
17:24		O	"Setpoints change to zero."	D	"Empty the tank now."
18:51					**R1 heated empty**

Comments: The subject had no problem with the reservoir 1 leak. However, he never appeared to detect or understand the nature of the second fault (increase in

input temperature). He spent most of the trial after fault 2 fine tuning H1 and H2 but never seemed to be happy with their settings. Hence, most of the trial was spent compensating for fault 2. He thought that the leak was causing his problems with H1. The fact that AS did not notice the problem with the water input temperature suggests that he has no expectations about what H2's setting should be.

Post-hoc: "I died, again." He is referring to his frequent blowups. He said that he did not understand why he overheated the reservoir. He said that he noticed the fault by the water level in R1 dropping (he remarked that he nearly missed it). Aside from the leak, he said "everything was fine". He did not notice the heater fault.

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: AV
Interface: EID
Initial Conditions: System was in steady state when fault occurred. VA1=6, VA2=3 and VB1=0, VB2=10. V1=50% and V2=70% (and increasing). H1=5 and H2@3

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:44	"Something very weird."				
:48		I	"This thing (*R1*) lost water all of a sudden, how come?"		
:55		I	"It keeps losing water."	E	H1 increase
1:00			"This is ridiculous."	E	H1 fine tune
1:18			"What the hell...?"		
1:30		I	"Now I still have some problem."		
1:39			*Setpoints change.*		
1:40			"Here we go."	E	VO1, VO2 set to new demands
1:42				E	H2 decrease
1:45				E	VA2 off, VA1 to full
1:50			"OK"	E	H1 to full
1:55				E	VO2 fine tune
1:57			"Still do the same thing." *Perhaps he is still compensating for the fault.*		
2:00	*(Second fault begins.)*				
2:05				E	VA1 to 8
2:14				E	VA1 to 10 (*The subject seems to be experimenting to see the effects of changing input flow.*)
2:15		O	"Come on guys that's not fair. It's (*R1*) still going down."	E	VO1 fine tune
2:28				E	H1 fine tune
2:30			"Oh stupid (*unintelligible*)."	E	H1 increase
2:33				E	H2 fine tune
2:56				E	H1 fine tune, H2 fine tune

3:00	"Oh shoot, I got it." (*The subject points to the input temperature gauge)*		"Oh gosh, go figure."	E	H1 decrease, H2 decrease
3:16		I	"I think this thing (*input temperature*) is too high." *Subject circles input thermometer with mouse.* "Oh you guys, you're cheating again."		
3:23				E	VO2 fine tune
3:26			"Oh, fuck off."		
3:30				E	H1, H2 fine tune
3:36			"That's (*the fault*) not fair."	E	VA2 decrease
3:43				E	H1 fine tune
3:55			"Oh come on you stupid jerk (*apparently talking to H1*)" *Subject just exceeded the limits of the T1 goal area.*		
4:08				E	H2 decrease several times
4:16				E	H2 decrease several times
4:36				E	H1 fine tune
4:51				E	H2 fine tune several times
5:18			"Oh shoot, oh." (*The subject may have fallen out of steady state*)		
5:20		I	"Let's recap what happened. This thing (*points to R1*) start losing water over here and the heat over here (*input temperature gauge*) went too high, so that's why I screwed up so much. I don't remember what time it was (*when the second fault happened*)."		
5:47				F	"Pull this guy down (*unintelligible*)"
5:48				E	VB2 decrease
6:05				E	*The subject fine tunes heaters for the remainder of the trial.*
8:48					*System shutdown begins. Unlike many of his other trials AV does not anticipate shutdown*

Comments: AV detected both faults and diagnosed while compensating. He stated that R1 was losing water and the input water temperature was too high. He may have lost track of his steady state time and hence did not anticipate shutdown.

Post-hoc: "Two things you weasels: the temperature was too high from the incoming water and the first reservoir started leaking." He said that these faults "screwed up the whole thing". He compensated when he "tuned the temperatures and put more water in the first reservoir." The reservoir leak was noticed by the water level going down. AV's last statement for this trial was: "Don't do it again, I don't like it. It gets on my temper."

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: TL
Interface: P&ID
Initial Conditions: System appears to be in steady state. VA1=6, VA2=2 and VB1=0, VB2=10. H1, H2@5. R1, R2 about half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:40	"What's happening here?"				
:45		O	"Water seems to be going down." (*Subject does not indicate where.*)		
:50				E	VA1 increase to 8
1:03				E	VA1 increase to full
1:12				E	H1 increase
1:14				E	H1 increase
1:36				E	VA1 double check at full
1:38				E	H1 to full
1:42			"What's happening on reservoir 2?"		
1:51		I	"Seems to be going all right in reservoir 2."	D	"Back to reservoir 1."
1:58				E	H1 to 8
2:00	*(Second fault begins.)*				
2:15		O	"Still going down (*R1*). What to do about reservoir 1?"		
2:30				E	H2 decrease
2:45				F	"We can decrease this (*VA2*) by 2."
2:47					VA2 decrease
2:50				F	"Increase this by 2 (*VB1*)"
2:52				E	VB1 increase (*The subject is using feedwater stream B to supply more water to reservoir 2 so that feedwater stream A goes completely to reservoir 1*)
2:55				E	H1 increase
3:00	"What's happened here?"	I	"...(*R2*) heat kinda went nuts on reservoir 2."	E	H2 decrease
3:20				E	H1 to full
3:32				E	H1 decrease

3:35				E	H2 off
3:49				E	H1 to 5 (*The subject is reacting to increase in input water temperature.*)
4:06				E	H2 to 4
4:16				E	H1 increase
4:24				E	H2 decrease
4:28				E	H1 increase
4:38				E	H2 decrease
4:42			"Very hard to adjust the heat when you don't know what's going on."	E	*The subject fine tunes the heaters several times.*
8:44				E	*Demand pairs change. Subject appears to set valve and heater settings according to his rules. Just before doing this he says:* "Let's see what this gives us." *He then proceeds to make the changes.*
8:46		I	"That (*configuration*) doesn't seem to be working."		
9:50				E	VA1 to 5
9:57				E	H1 decrease.
9:59				E	H2 off
10:11				E	H1 increase
10:14				E	H1 increase
10:33				E	VA2 increase
10:35				E	VB1 decrease
10:44				E	H1 increase
10:59				E	H2 increase (*The subject fine tunes heaters through to the end of the trial.*)
12:00			"Well, pretty much with the pump and heater malfunctions, just using empirical science here." *The fact that he notes a problem with the pump indicates that he does not recognize that if the pump were broken then, given his coupled feedwater streams, both reservoirs would be affected , not just R1.*		
16:38					*System shutdown begins.*

Comments: TL detected both of the faults but never got beyond compensating for them. He spent most of the trial fine tuning components.

Post-hoc: "The valves and heaters did not behave. Hold on, the input water did not behave." He just noticed this after the trial ended. He also thought that the "Valves were not working right." In the post-hoc discussion he noted that his rules for system operation did not work for this trial. When the he was asked "*What took the long time?*" he responded, "All the old rules don't work anymore, so we're back to empirical science; just seeing what works."

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: WL
Interface: P&ID
Initial Conditions: System appears to be in steady state when first fault occurs. Volume and temperature may not be stable. VA1=3, VA2=6 and VB1=3, VB2=6. H1, H2@5.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
					Just after the first fault, subject increases VA1 and VB1 in order to get more water into R1. Following this he increases H1 to full then to half and back to full.
					Just after the second fault happens the volume in R1 is slowly increasing and he frequently fine tunes H1. He makes several large changes to the heaters both increasing and decreasing settings. He appears to be experimenting with the settings.
12:36					*The subject puts mouse pointer on input water temperature meter.*
14:41					**R2 heated empty**

Comments: While the subject did the trial, he did not verbalize detection. However, from his actions and post-hoc discussion, it seems that he did detect both of the faults (even though he confounded them).

Post-hoc: "That's more difficult, because the input here is 15." WL mistook temperature for input flow rate by misinterpreting the input water thermometer. He thought that the input water flow had changed to 15. "I noticed that (*the input was 15*) in the middle of the trial." He said that he set input equal to output but the water level still dropped. Assuming that WL knew from past trials that maximum input water flow was normally 20 units/second, his erroneous hypothesis that the input flow rate was only 15 (meaning a net loss in flow of 5 units/second) came close to explaining the leak of 4 units/second on R1. However, his hypothesis did not explain why R2 was not affected, as it should have been, had the main input water stream really been decreased. He also stated that something may have been

wrong with reservoir temperature during shut down, but that it was not relevant.

Trial: 201
Fault: 4 minutes after start of trial, R1 begins to leak at a rate of 4 units/second. At 6 minutes after start of trial, input water temperature begins to climb exponentially to 16 degrees. (D1=5, D2=11 change to D1=6 and D2=9).
Subject: ML
Interface: P&ID
Initial Conditions: Appears to have the system in steady state. VA=8, VA1=3, VA2=6 and VB=8, VB1=3, VB2=6. H1=5, H2@3. Reservoirs are about 20% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:16					R1 heated empty

Comments: Due to low volumes the subject did not notice the first fault in time and R1 overheated because there was no water in it.

Post-hoc: "Reservoir one started losing water, I assume that one of the valves was screwed up." The subject thought that the fault was that one of the secondary valves were blocked.

TRIAL #209

Summary: non-routine fault (valve block and external heat source)

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: IS
Interface: EID
Initial Conditions: System is at steady state when fault occurs. VA1=4, VA2=0 and VB1=0, VB2=5. H1=5, H2=2. V1=60%, V2=30%.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:14		I	"Reservoir 1 shut down." (*There is no flow to R1 because VA is blocked and VB1 is off.*)	E	VB1 to 4
:18				D	"So I'm going to bring it over from reservoir 2." *Subject intends to bring water from FWS B to supply R1.*
:31				E	VB2 increase slightly
:37		I	"I think it's OK."	E	H1 decrease
:41					**PA blows up**

Comments: The subject compensated without diagnosing. Had he diagnosed first, he may have had a chance of turning VA off in time. He also focused on the right half of the display, hence he did not notice the loss of flow on VA. Because he had VA2 closed, it was impossible to tell if VA or VA1 was blocked.

Post-hoc: "I guess there was a plug somewhere." He noticed that the water level was dropping as well as the flow rates dropping on the VA and VA1 flow meters. He thought that R2 was also losing flow. Given his system configuration (i.e., FWS A was not supplying any water to R2), his belief that R2 was losing flow was wrong.

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: AS
Interface: EID
Initial Conditions: System is at steady state when the fault happens. VA=5, VA1=5, VA2=7 and VB=6, VB1=6, VB2=6. H1=5, H2=2. Reservoirs are 50% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Setpoints change (4 seconds before fault).				
:38					**PA blows up**

Comments: Subject was concentrating on satisfying the new demand pairs. He was focusing on the right half of the display and did not notice the drop in flowrate on VA.

Post-hoc: After having looked at the screen for several seconds after the simulation ended, he said that the problem must have been with VA. He said that after the demand pairs changed the valves looked OK, so he focused on the mass/energy balances.

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: AV
Interface: EID
Initial Conditions: System is at steady state when the fault happens. VA1=7, VA2=10 and VB1=0, VB2=4 (decoupled FWS). H1, H2 both off since temperature goals are being met with surplus heated water. R1, R2 both full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:00	*(Second fault begins.)*				
3:40					*System shutdown begins.*

Comments: Due to the relatively low demands, the subject was able to fill up and heat both reservoirs before the fault. Just before the fault, he turned off the pumps and heaters and let the reservoirs drain at the demand rate. Since he used this strategy he never saw the effects of VA blocking. He also did not detect the second fault. The external heat source was very small and hence, had a negligible effect on T2.

Post-hoc: None.

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: TL
Interface: P&ID
Initial Conditions: System appears to be at steady state when the fault happens. VA1=3, VA2=0 and VB1=0, VB2=4 (decoupled FWS). H1@3, H2@2. Reservoirs are both 66% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:32	"Oh, what happened?"				
:41					PA blows up

Comments: The subject did not notice the fault in time to diagnose it.

Post-hoc: "I'm not quite sure what happened. I noticed water going down a bit and the heater going up (*due to less water coming in*)." He then tried to compensate with the heater. In the post-hoc discussion, he eventually deduced that the valve must have been blocked.

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: WL
Interface: P&ID
Initial Conditions: System approaching steady state when the fault happens. VA1=2, VA2=2 and VB1=2, VB2=3. H1@5, H2@2. Reservoirs are both 66% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
				E	*Demand pairs change 23 seconds before fault. Subject is in the process of reconfiguring system to satisfy new demand pairs.*
:41					**PA blows up**

Comments: Subject did not detect the fault at all.

Post-hoc: Subject had absolutely no idea what happened: "Everything was going normally" before it blew up.

Trial: 209
Fault: 7 minutes after start of trial, VA becomes blocked. Flowrate through valve begins to drop exponentially to zero. External heat source begins to add heat to R2 at a rate of 3e3 watts at 8 minutes. (D1=5, D2=6 change to D1=3, D2=4).
Subject: ML
Interface: P&ID
Initial Conditions: System appears to be at steady state when the fault happens. VA=6, VA1=6, VA2=6 and VB=6, VB1=6, VB2=6. H1=6, H2=2. Reservoirs both have very low volumes (about 20%).

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Just before the fault the subject is adjusting H1. He turns it off just before he says:				
:21	"What the hell is going on here?"				
:24			"Some things are wrong there." *Presumably somewhere around PA, judging from where the mouse pointer is."*	E	PA off, VO1 off
:32				E	VB to full
:36			*The subject compares the input flowrates and output flow rates.*	E	H2 off
1:04				E	VO1 to 3
1:17				E	H1 increase
1:24			*(unintelligible comment)*		
1:30				E	VA1, VA2 to full
1:34				E	VA to 1
1:39				E	H1 decrease
1:42				E	H2 fine tune
1:46				F	"I don't know what's going, I'm going to try it (*PA*)."
1:51				E	PA on
1:56					**PA blows up**

Comments: The subject detected the fault in time to initially avoid PA blowing up. He guessed and turned off PA when he noticed something wrong. However, he was unable to diagnose the fault and turned PA back on, causing it to blow up.

Post-hoc: "The water started dropping all of a sudden. I don't know why I decided that it was this one (*PA*), but for some reason I turned it (*PA*) off." He then tried to satisfy all demands with PB, but he said that he could not because they summed to 11. He tried to get a little more out of PA, so he turned it on again and it blew up.

TRIAL #218

Summary: non-routine fault (heater fault and increased input water temperature)

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: IS
Interface: EID
Initial Conditions: System is in steady state. VA1=7, VA2=2, VB2=10. H1=7, H2=4. R1 and R2 are approximately a half and a quarter full respectively.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:07	"That's interesting."	O	"Heater 1 has decided to skyrocket for no particular reason."		
:15				E	H1 to 7 then to 2
:22		I	"Reservoir 2 is behaving normally."		
:40		I	"That's (*H1*) the only problem and it's manageable."		
:42				E	H1 fine tune
:57		I	"OK perfect that's (*H1*) fine, no problem."		
1:11		I	"Reservoir 2, again, is behaving normally."		
1:16		I	"The only problem with reservoir 1 is with the heater setting, but that's manageable."		
			The subject has system in steady state before second fault.		
2:00	(*Second fault begins.*)				
2:05	"That's ironic."	I	"Heater 2 is doing the same (*as H1*)." *Subject is not exactly correct, the causes are different.*		
2:08				E	H2 decrease
2:17		I	"Heater 1 is acting up again even more." *Due to the effects of the second fault H1 appears to be worse.*	E	H1 decrease several times
2:29				E	H2 decrease
2:34			"Darn it."	E	H2 off
2:36				E	H1 off
2:43				E	H1 to 4 (*He appears to be getting the energy gradient vertical for R1*)
2:46				E	*Checks that H2 is off.*

2:56			"So I lost equilibrium on heater 2, I thought I had it in time (*circles T2 with pointer*)" *Subject went outside of the goal area for T2.*		
3:08				E	VO2 increase
3:11				D	"Let's just increase input a little."
3:13				E	VA2 increase
3:28				E	H1 fine tune
3:49				E	H1 fine tune
3:57				E	VA2 increase
4:06				E	VO2 increase
4:26				E	VO2 fine tune
4:30				E	H1 fine tune
4:43				E	VO2 fine tune
4:56				E	VA2 decrease
4:58				E	H1 fine tune
5:06		I	"OK, so I now know what the problem is, the reason the heaters started behaving abnormally was because the water temp before heating was higher than normal."		
5:27				I*	"So how does that help me get the temperature down to within reason, it doesn't really."
5:44		O	"I'm just barely in the limit (*T2 goal*) on reservoir 2." *H2 is off.*		
6:09				E	H1 fine tune
6:24				E	*Subject fine tunes valves and heaters.*
7:53		O	"For the life of me I'm really puzzled about this one, and the settings have changed."	E	*Subject reconfigures valves for new setpoints. Subject leaves H2 off.*
8:44		O	"That should be about right." *He has achieved new steady state.*	E	H1 fine tune
8:52				E	VB2 increase to 10 (*instead of 9*)
9:06				D	"Right now I'm just experimenting to see what happens if I put too much water in the system(*R2*).
		O	"And think I don't like the answer."	E	H1 fine tune

9:49		O	"Yeah, there's just no way to raise or lower the temperature on reservoir 2." *Subject is experimenting to see if adding water to R2 will have a cooling effect. It doesn't, because it is the input water itself which is hotter.*	E	VB2 decrease to 9
9:55				D	"I'll just leave the input (*VB2*) and output (*VO2*) equal to each other"
10:00				E	*The subject tries clicking on input water thermometer. There is no effect because this cannot be modified by the subject.*
				E	*The subject fine tunes the system and waits for shut down.*
13:07		O	"Finally, time to shut down."		

Comments: IS detected fault #1 quickly and compensated for, but did not completely diagnose the fault. He did however, completely diagnose the second fault but only after compensating for it.

Post-hoc: "It's counter-intuitive. Heater 1 started skyrocketing so I had to turn down the settings on H1...it was stable for about 2 minutes and then what happened was that the input water temperature went and I just thought that it was the same problem as before (*same as the first fault*), that it was a heater problem, so I ignored it at first. So, reservoir 2 overheated before I had time to turn off its heater completely because the input temperature was the temperature that H2 was supposed to be stable at."

IS first noticed the fault on H1 because the heat transfer rate started to go up and he knew from past experience that it was wrong, so he compensated. This worked until the input temperature went up as well. He noticed the second fault because the temperature on R2 started going up. He then noticed the input water temperature gauge, which he said he "never looked at before". At this point, IS noticed that the input temperature was out of the green goal area. When solving faults, he said that he tends to react first and then diagnose the problem. However, on normal trials when events occur, such as the change of demand pair settings, he said that he plans his actions ahead of time. He gives the example of D1 changing from 5 to 10. From this new demand he immediately knows that he has to increase flow

and temperature. So he increases input to R1 to 10 and guesses what H1 should be. He then fine tunes until temperature goals are satisfied.

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: AS
Interface: EID
Initial Conditions: Steady state achieved. VA=10, VA1=6, VA2=10, VB=9, VB1=5, and VB2=10. H1=7 and H2=4. Both reservoirs about half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
				E	*After the fault, AS changes the setting of H1 several times and says:*
:30	"Hmmm..."	I	"It looks like something is wrong with the heater (*H1*)"		
:40				E	H1 decrease
:52				E	H1 increase
:58				E	H1 decrease (*several times*) *AS appears to be experimenting with H1.*
1:10		I	"OK, I think the problem with the heater is the actual temperature is higher than what is shown on the setpoint."		
1:28		O	"It's (*H1 heat transfer rate*) always overshot by one third or something like."	E	H1 decrease
1:41		O	"It's (*the fault*) only happening to reservoir 1."		
1:52				E	H1 decrease and fine tune
2:00	(*Second fault begins.*)				
2:12		O	"It's (*H1*) still increasing. Holy cow, what's happening?"		
2:14				E	H1 decrease
2:15		I	"Whoa, now it's happening to both (*heaters*)."	E	H2 off
2:25				E	H1 increase
2:26		O	"The heater temperature setting doesn't correspond to the setpoint anymore."		
2:33				E	H1 decrease
2:45				D	"I'm going to need more water in reservoir 2."

2:47				F	"So I'm going to close the output valve just to accumulate more water in order to lower the temperature." (*He is trying to cool the water presently in the reservoir with new water. This will not have much of an effect because the input water is now hotter due to fault #2.*)
3:14				E	VO2 to 12 (*The subject then fine tunes it down*)
3:44		O	"The heater (*H2*) is off and still showing overshooting (*the temperature goal for reservoir 2*)." *This may be due to left over hot water from before the fault.*		
3:50				D	"Put more water into reservoir 2."
3:55				E	VO2 off
4:07		O	"There we go, OK the heater temperature drops back to the green setpoint region. I think that we've lost a lot of time on this one."		
4:25				E	VO2 fine tune
4:27		O	"The flowrates are now again in steady state, so is the heater temperature so the system is back in steady state again, I hope."		
4:41				E	VO2 fine tune
5:03				D	"I'm creating a flow rate gradient in here (*mass balance in R2*) so that I can have temperature gradient as well (*points to energy reservoir 2*). Looks like I will not have both a steady state flow rate...reservoir 2 the input temperature is very close to the output temperature even without adding heat." *From his actions it appears as though he is trying to get both mass and energy gradients vertical, but is having trouble keeping both of them vertical at the same time.*
5:46		I	"By creating a net output in reservoir #2, that means that water is keep cycling in reservoir 2." *Subject circles the mouse pointer several times in R2 graphic. Perhaps he thinks that the water is cooling due to the net output in R2.*		
8:39			"Still waiting for setpoints to change."		

9:18					*Setpoints change. Subject adjusts valves to meet new demands. He fine tunes H1 down several times but never modifies H2.*
10:54		I	"The system has sort've reached steady state. Waiting for the setpoints to go to zero." *He appears to be in steady state.*		
12:18			*Setpoints change.*		
14:29			*Setpoints change to zero.*		
15:41		O	"Looks like reservoir 2 may overheat."		
15:43				D	"That's why I am closing reservoir 2 right now, and just let more water into reservoir 2 and hopefully the temperature will drop." *AS typically does not begin to empty the reservoirs during shutdown until the water temperature drops below the green goal region (water temperature normally decreases during shutdown because the heaters have been turned off). However, in this case the input water is coming at the goal temperature, hence, water temperature in R2 remains in the goal region even when the heater is off. This means that AS's cue for emptying R2 will never occur. It should be noted that the use of this cue is incorrect. AS should be cueing on the heat transfer rates on H1 and H2, when these drop to zero then the reservoirs can be completely emptied - it has nothing to do with water temperature.*
15:45				E	VO2 off
17:17				F	"I'm going to take my chances, I'm going to switch off the pumps (*and empty reservoir 2 even though temperature is still high*)." *The subject begins to empty reservoirs.*

17:55		O	"The temperature is not dropping." *At this point, R2 is almost empty, there is almost no energy left in the system and R2 has been off for most of the trial (because the input water is coming in at the goal temperature for R2). However, the water is still the same temperature. Again, he is confusing temperature with energy and heat transfer. Subject thinks that the reservoir over- heats if the water temperature is too high. This is incorrect. The reservoir over-heats if energy is still being transferred to the reservoir when it has no water in it. This perhaps helps to explain this subject's high number of blowups due to the reservoir being heated empty: he does not understand the temperature dynamics.*		

Comments: The subject detected, diagnosed and compensated effectively for the first fault. However, the second fault confused him. He could not understand the effects of the hotter input water on the system; he confused these temperature effects with heat transfer effects of the heater. He never diagnosed the second fault.

Post-hoc: "Two things: first the heater settings were strange. It looks like the actual temperature doesn't reflect the setpoint." He thinks of the heater gauge as a thermometer instead of the heat transfer rate. This contributed to his problems diagnosing the second fault. "After a while both reservoirs have the same behavior." This is incorrect: the effects on R2 are only from fault 2, R1 is affected by both faults.

The subject is able to recognize that the input water was hot enough to satisfy demands because he usually needed to use the heater to heat up the input water to get the "temperature line (*energy gradient*) vertical". After discussing this fault for a few minutes, the subject realized that, in light of the hotter input water, the high reservoir temperature now makes sense.

He noticed the fault because the energy balance graphic gained a positive slope. He said that he ultimately compensated for the fault by "trial and error".

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: AV
Interface: EID
Initial Conditions: VA1=10, VA2=3 and VB1=0, VB2=10. H1=7 and H2=4. Reservoirs volumes low, about one third full. When the fault happens the system is in steady state with reservoir volumes increasing.

Time after fault (min:sec)	**Detection** **Activation**		**Diagnosis** **[O]bservation** **[I]dentification**		**Compensation** **[D]efine Task** **[F]ormulate a procedure** **[E]xecute** **[I]nterpret***
:14	"Oh, gosh, shit." *Subject quickly moves mouse pointer to H1*		"Why do you do this thing now?" *He is complaining about the fault.*	E	H1 off
:25				E	H1 to 7
:29			"Jesus Christ guys, that's cheating." *Subject is complaining about the fault again.*	E	H1 to 5
:39				E	H1 to 6
:45				E	H1 to 5
1:11				E	H1 fine tune
1:21				E	H1 fine tune
1:48				E	H1 fine tune down
1:50				E	H1 fine tune to 5
2:00	*(Second fault begins.)*				
2:09				E	H1 to 2
2:10	"Awww, you guys!"			E	H2 to 2
2:17				E	H2 off
2:24				E	H1 decrease
2:30				E	H1 to 5
2:40				E	H1 fine tune
2:45				E	VA2 increase
				E	*The subject makes several changes to H1 first decreasing it and then increasing it and then fine tuning for the next several minutes.*

5:22				E	*Demand pairs change. Subject quickly changes values to compensate; he does not touch either heater (just before demand pairs changed he decreased H1 which inadvertently helped him on the new demand pairs).*
7:11				E	H1 fine tune
7:55				E	H1 off
8:02				E	PA off (*R1 is completely full and heated to goal temperature*).
8:42				E	VO2 and VB2 fine tune
9:28			"All right."	E	PB off
9:40				E	*The subject closes all input valves. R2 is now completely full and heated to goal temperature.*
10:30					*System shutdown begins. Subject has successfully anticipated shutdown.*

Comments: The subject noticed both faults quickly and compensated very quickly for both of them. He did not explicitly diagnose either fault. In fact, he spent more time complaining about the fact that there was a fault than verbalizing his diagnoses. AV completed this trial several minutes faster than any other subject.

Post-hoc: "You screwed up the first thermostat (*he is referring to H1*) or whatever it is - it (the temperature) went up higher than it should." "The thing got screwed...the temperature controller. And then the water temperature went up." The subject noticed the first fault because he said that the "indication went up" and for the second fault "the indication went up with the water too". When asked what he did to compensate he said: "I just put the temperature down, I turned it off on the one downstairs (*H2*)". Thus, despite the lack of verbalizations during the trial, he seems to have diagnosed both faults.

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: TL
Interface: P&ID
Initial Conditions: System appears to be in steady state. VA1=7 and VA2=3, VB1=0 and VB2=10. H1=7 and H2=4. V1=25% full and V2=50% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:14	"Aaaah nuts!"			E	H1 decrease to 6
:28				E	H1 off
:43				E	H1 to 7
:45				E	VA1 to 5
:56				E	VA1 to 7 (*The subject appears to be trying to control temperature with input water.*)
1:03				E	H1 to 6
1:10				E	VA2 decrease to 2
1:11				E	H2 decrease
1:16				E	VA1 increase
1:18				E	H1 decrease to 5
1:28		I	"Boy I'm mucking this one up pretty bad." *Subject is having trouble stabilizing the system temperature.*	E	V01, V02 fine tune
1:50				E	H1 fine tune
2:00	(*Second fault begins.*)				
2:07				E	H1 to 5
2:16				E	H2 decrease twice
2:28	"I get it..."	I	"The input temperature is off the scale. That's nuts."	E	H1 decrease to 2
				E	*The subject fine tunes heaters for next several minutes.*
4:00				E	*The subject experiments with H2, clicking it off to about 2 to off again to see if it is needed. He eventually leaves it off. For the next several minutes he primarily fine tunes H1 and VO1. He occasionally fine tunes other valves but never H2.*

12:35				E	H2 off (*verifies*)
13:32				E	H1 off
13:47				E	PA off
14:02				E	PB off (*Both reservoirs are almost full. He appears to be anticipating shutdown. He has enough water in his reservoir to satisfy demand until shutdown occurs. By anticipating shutdown he can cool his heaters early and finish the trial faster*)

Comments: TL compensated by trial and error after detecting the faults. He never diagnosed the first fault. When the second fault happened he noticed that the input temperature was too high. He then diagnosed this as the root cause of all of his problems. He never realized that H1 was broken as well. Like subject AV, he successfully anticipated shutdown by filling up the reservoirs and turning off the heaters before demand pairs changed to zero. However, TL's time was considerably longer.

Post-hoc: "Input temperature went way out of range." "Things got too hot and I had to cool it down." TL noticed the fault because he "reached steady state and the temperature in the reservoir was going up". He remembered that an input temperature fault had happened on a previous trial (cf., trial 201) and, given the similar symptoms on this trial, he diagnosed that the input water was entering the system hotter than usual. What helped him diagnose this was the heater setting that he normally used for the given demands did not work. He said that he compensated by trial and error.

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: WL
Interface: P&ID
Initial Conditions: Appears to be in steady state. VA1=4 and VA2=6, VB1=4 and VB2=6. H1=7 and H2=4. Reservoirs are about half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Just after the fault happens, the subject turns off H1 and then on to about 7 and repeats this several times. He then appears to experiment with the settings for H2 but quickly returns to experimenting with H1. 2:12 after the first fault he turns off H1. Soon after this he says:				
2:00	*(Second fault begins.)*				
3:06	"How come?"				
3:19				E	H1 to 4
3:21				E	H1 off
3:28				E	H1 to 4
3:35				E	H1 to 5 *(and clicks repeatedly on H2 to make sure that it is off)*
4:00				E	H1 off
4:06		O	"I notice that input temperature is hotter than normal"		
4:14				F	"That's why I have to *(unintelligible)* the heater a little bit."
4:21				E	H1 to 4
4:28				E	*Clicks H2 about 15 times to make sure it is off (it is).*
4:34				E	H1 to 10 then to 5 then off.
5:18				E	H1 to 4 *(clicks repeatedly to make sure it is set)*
5:50				E	H1 off
6:04				E	H1 to 4 *(clicks repeatedly to make sure it is set)*
8:14				E	*Demand pairs change and the subject efficiently adjusts output and input valves to accommodate.*

8:33				E	H1 off
8:37				E	H1 to 3
9:04				E	H1 off
9:10				E	H1 to 3
13:23					*System shutdown begins.*

Comments: (Throughout the trial, the subject repeatedly clicks on many of the components with out changing their settings: he seemed to want to be absolutely sure that they are set correctly.)

The subject appeared to detect the first fault because he changed the setting of H1 drastically several times and continued to fine tune H1 repeatedly. However, he did not say anything. When the second fault occurred, he went through similar motions. Two minutes after the second fault, he verbalized his detection and compensated for the remainder of the trial.

Post-hoc: "The input temp is 40 instead of 20." The subject did not read the input temperature scale carefully, the input temperature was in fact 21 instead of the usual 10. He did, however, recognize that the input water was about twice as hot as expected. He said that he noticed the fault because the heater setting had to be lower than normal for the given demands. He also said that he compensated before diagnosing, in order to save time.

Trial: 218
Fault: 3 minutes after start of trial, H1's output begins to increase exponentially until output is 150% of the setting. At 5 minutes after start of trial, input water begins to climb exponentially to 21 degrees. (D1=7, D2=12 change to D1=5 and D2=9).
Subject: ML
Interface: P&ID
Initial Conditions: System appears to be in steady state before the fault. VA1=4 and VA2=6, VB1=4 and VB2=6. H1=7 and H2=4. Reservoirs are both about 20% full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Just after the fault, the subject fine tunes H1 and then turns it off.				
:34		O	"It's (*T1*) going up?"		
:42				E	H1 to 4
:40				E	H1 to 7 (*The subject seems to be testing if the expected setting is valid.*)
:50		I	"This one (*T2*) seems to be OK." (*moves pointer to R2*)		
1:10				D	"7" (*set H1 to 7; this setting will be too high*)
1:14				E	H1 to 6
1:16				F	"5"
				E	H1 to 5
1:17				F	"3.5"
				E	H1 to 3.5 (*The subject is trying to find ideal heater setting by trial and error.*)
1:49				E	H1 to 5
2:00	(*Second fault begins.*)				
2:03				F	"6"
				E	H1 to 6
2:05				F	"5"
				E	H1 to 5

2:14	"Ahhh..."	O	"And now this one (*H2*) is doing it too. OK there's something wrong with that. The water levels aren't really changing." (*If they were, say due to a leak or blocked valve, then this would affect temperature. Subject is evaluating possibilities for the cause of the fault.*)	E	H2 decrease
2:26				E	H2 decrease.
2:31				E	H1 off
2:36		O	"Or are they?" (*Are the water levels changing?*)	E	H2 off
2:38		O	"This is around 20 and this is around 18." (*He is referring to the levels of R2 and R1. He will likely keep an eye on these levels to see if they are changing.*)		
2:46				E	H1 to 4
2:54		O	"Still around 20 and 18, water levels aren't changing."		
3:05		I	"It's not too bad with 4 up here instead of 7." (*The setting for H1 seems to work for the given demands, whereas a setting of 7 would normally be used.*)		
3:14				F	"And this one (*H2*) very slow, try (*setting it to*) 1."
3:15				E	H2 to 1
3:26		O	"It's going up again." *T1 is still rising.*	E	H1 to 1
3:30				F	"Try 3.5"
3:32				E	H1 to 3.5
3:51		O	"This one's (*R2*) still hot with (*setting 1 for H2*) 1. Only a fraction."		
3:58				F	"(*unintelligible*) about half."
3:59				E	H2 to .5
4:05				F	"(*unintelligible*) looks still no good. How about 3?"
4:07				E	H1 to 3
4:23				E	H1 to 2.5
				F	"2.5"
4:28				E	H1 decrease
4:31		O	"That's (*H2*) just barely on."	E	H2 decrease
4:45				F	"Ahhh, off."
				E	H2 off

5:00				E	VA fine tune down
5:02				E	H1 fine tune down
5:50				E	V02 to 20
5:56				E	VO2 to 12
6:12		I	"Very strange."		
6:17				E	VO2 to 20 then to 12 (*The subject appears to be trying to lower the volume of R2.*)
6:32		I	"This (*H1*) seems happy with (*setting*) 3. This (*H2*) seems almost happy with (*setting*) 0." *Temperature goals are being achieved with these heater settings.*		
7:09		O	"15 and 19" *He is noting the levels of R2 and R1 respectively.*		
7:17				E	VO2 to 10 then to 7
7:37				E	VO2 to 10
7:42				E	VO2 to 7 (*he might be experimenting to see if one of the valves is causing the temperature problems*)
8:00			"(*unintelligible*) actually."		
11:02		I	"This thermostat (*he is referring to H1 with the mouse pointer*) went haywire, and then this one, (*points to H2*) because the water levels didn't change. (*And*) it wasn't a problem with the water levels, and it wasn't a problem with the valves because it (*water flow*) was going out and coming in just fine. It was just the temperature of the water went screwy. It (*the temperature of the water*) started going way up and I eventually found that around 3 (*H1 set to 3*) it seemed to stabilize here and this one (*H2*) was (*set to*) zero. So something stuck or went wrong with the thermostat (*he calls the heaters thermostats*)." *In the video he appears to be talking about the temperature of the reservoir water, not the input water.*		
11:43					*Demand pairs change and the subject efficiently adjusts valves for new demand pairs.*
12:26				E	H1 to 1
12:28				E	H1 to 3

12:30				F	"Somewhere around 3 maybe." (*he means that setting H1 to about 3 should satisfy new temperature demands*)
12:42			"I didn't realize it was the second one to go" (*he realizes that he has to complete tuning as well*)	E	*The subject fine tunes input valves and H1*
20:05			*Just before the reservoirs are emptied for shutdown, the subject keeps closing VO1 and VO2 and refilling the reservoirs. Apparently he is trying to get the reservoir temperature down: it is higher than normal due to the higher input water temperature.*	D	"I'll just have to let them (*reservoirs*) drain out - I don't know what else to do."

Comments: ML detected and then compensated for both faults using trial and error. He erroneously deduced that both heaters were broken because he observed that there was not a problem with input and output flow rates and both reservoir levels were stable indicating that there was not a leak.

Post-hoc: "Temperature started going up on the top one (*R1*)." "The temperature started going up on the second one, not at the same time. So I fiddled and fiddled." He noted that during shutdown the temperature would not go down, so he deduced in the post-hoc discussion that the water must have been coming in at about "double temperature".

TRIAL #223

Summary: transfer fault (heater), see baseline trial #97

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: IS
Interface: P&ID
Initial Conditions: H1 on maximum, H2 on 4. VA1, VB2 full. VA2 on 2 and V02 at 12 (same as D2). Subject has system at steady state before the fault happens. All he has to do is wait for T1 to reach the goal area.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
1:08		O	"Curious at how slowly reservoir 1 is taking to get to the temperature."		
1:22		O	"Usually it (*T1 at goal state*) is there by now."		
1:26				D	"Increase input, that usually speeds it up." (*He wrongly assumes that by adding more water to R1 he will increase the temperature. He is getting temperature and energy mixed up: adding water will increase the energy in the reservoir but lower the temperature.*)
				E	VA1 increase
1:40		O	"Well that's not speeding it up, it's even dropping."		
1:57			"So what could it be?"		
2:07				E	VO1 fully open
				D	"I'm just going to dump some water to give myself some room"
2:30				D	"OK, let's set it back (*output*) to a little below (*the goal area itself*). Now what can be done?"
				E	VO1 decrease
3:17		O	"I just cannot get it up to proper temperature settings...it's very odd."		
3:28				E	H1 to maximum
3:30			"completely counter-intuitive"	E	H1 to off
3:32				E	H1 to maximum
3:44				E	VA1 decrease
3:49				E	VO1 slightly increase
3:51				D	"Again I'm going to drop it (*R1 volume*)"

4:06				E	VA1 closed
4:24				E	VA1 to one third setting
4:32				E	VA1 to one quarter setting
4:34				E	VA1 to one third setting again
4:40				E	VO1 decrease
		O	"There we go, finally." *Temperature is increasing quickly now due to very low volume in R1.*		
4:49		O	"You should not still be dropping (*R1 level*)."	E	VA1 increase
4:54				E	VA1 increase
5:08				E	H1 gradually increased to 8 setting.
5:11				E	VA1 fine tune
5:22				E	H1 to maximum
5:23			"Now what happened there was I was able to get it up to temperature but then I just lost it completely." *This happened because he started adding water again which reduced his temperature.*		
5:40			"Very, very, annoying."		
5:52		O	"So I'm setting it back up (*temperature*)."		
5:59				D	"I remember almost the identical situation with the other system and I had to click temperature back and forth, but that really doesn't help me." (*he seems to be recalling how he diagnosed the similar error not how he controlled it (see description for IS trial #97 description)*
6:18		O	"It's not good at all." *He is referring to his continuing difficulty with T1.*		
6:24				E	V01 fine tune
6:40		O	"OK (*unintelligible*)" *T1 is approaching the goal region.*		
7:05		O	"So, I've got it (*temperature*) in range now but whatever that means, I don't know."		
7:16			"The setting won't change until about 13 minutes" (*five minutes from now; he has just achieved steady state*)		
7:26				E	H1 fine tune

7:45				F	"Well I know how I should've solved the problem in the beginning... and that was if I was dumping water from the reservoir, the temperature started going up since there was less water to heat, (*pause*) but I don't know at all what is wrong with the system." *He appears to begin an explanation of what he should've done in order to solve the problem but then can't figure it out.*
8:17		I	"I can only imagine that it has something to do with the heater (*H1*) - that the heater was not performing optimally. Certainly water input and output are behaving normally so that's the only thing."		
8:31		I	"That would be the problem. But again without a gauge I can't tell"		
8:48		I	"Well it must be it if I have to have the heater at 10 (*maximum*) to behave normally."		
9:41				E	H1 fine tune
10:40				F	"So I can't even begin to think about what I'm going to do when the settings change. If heater one continues to misbehave when the settings change then output for reservoir one has to go down, it can't go up, it can't handle the strain of that much output. We will see, I guess, fairly shortly." *He now has quite a good feel for the magnitude of the fault and how different demands will affect the ability to achieve temperature goals.*
11:42			"OK the torture is over."		

Comments: It took the subject a long time to diagnose the fault. He appeared to at first think that there was a problem with the input water temperature. After experimenting with this hypothesis, he ended up deciding by elimination that the problem was with the heater, but he was not confident with his conclusion. He spent the last four or five minutes of the trial (that is, after steady state was achieved) reasoning through the problem - looking for root causes not just reformulating rules. Not only was he concerned with completing this part of the trial, but he was also concerned with what he must do if the set points changed. At this point he is thinking ahead,

anticipating how the fault would affect the system and what he could do to compensate. It was also interesting to note that he ended the trial by saying "the torture is over". This strongly indicates the above normal effort that was required in order to complete this trial.

Post-hoc: He began by saying that "the heater wasn't up to snuff". "I had to keep the water level of reservoir one low. I routinely keep it over 50 (*half full*) but that was too high for the heater to heat". In fact this observation was incorrect. The heater could heat any amount of water in the reservoir successfully as long as the throughput of water through the reservoir did not exceed half of the heater setting.

When asked how he knew what the problem was he responded: "I knew that it was the heater's problem, but I didn't know in what way. I didn't know that the amount of water in the reservoir affected how fast temperature went up. So I dumped water out of reservoir one". After seeing the response to this tactic he then realized the relationship between volume and temperature (i.e., the lower the water level, the more responsive the heater). With reference to this property he said: "I had noticed this before but I had forgotten it." He said that with the other interface (EID) energy relationships are given graphically so that "you become more dependent on watching the graph than thinking about normal thermodynamics".

He summarized that "heater one was not performing up to capacity". "With this display (*P&ID*) it is a guess, you have no idea." It seems as though this subject relies on the graphics present in the EID display. Though by looking at his protocols, he seemed to eventually know what was happening functionally with H1. However, because the cues that he is accustomed to using for confirmation are not present, he is not confident with his diagnosis.

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: AS
Interface: P&ID
Initial Conditions: All input valves are open. Output valves are open to goal flow rates. Both heaters off.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	The subject never detects the fault. The following points highlight what he was doing during the trial.				
6:04	"The flow rate has almost reached steady state." *The subject only gets flow stabilized at this point. He then considers the heaters which have been off to this point. This is the first time that he has used this two-part strategy. He later says that he chose this method because he was not able to achieve steady state for the past two transfer trials (the simulations on these trials had to be stopped by the experimenter because the subject was unable to complete them in the allotted time).*				
6:23				D	"Time to adjust temperature now."
9:19		O	"The system is in steady state, I am waiting for the set points to change" *He is correct; he has just begun steady state.*		

Comments: The subject chose to use a sequential two step strategy for the first time during this experiment. Using this method he first stabilized mass flow and only then the temperature. Since he did not begin to stabilize temperature until after the fault, he never saw the effects of the heat transfer rate decreasing (e.g. by temperature decreasing). From this subject's verbal protocols from past trials, it is likely that he controls DURESS based on visual cues in the EID interface; he has no set rules that he follows when controlling the heater. For example, some other subjects know that, for R1, the heater should be set to the demand output rate in order to achieve temperature goals through steady state. On the other hand, AS does use

intricate calculations in order to determine what the settings should be for the input valves.

His input flowrate strategy typically begins by determining if D1 and D2 are less than 10. If they are, then and VB1 are set to D1, VA1 and VA2 and VB2 are set to D2. If on the other hand, either D1 or D2 are greater than ten, then VA1 and VB1 are set to half the value of D1 and the same is done for VA2 and VB2. Using this method the output demands are mirrored by the proportion of input water that is supplied to each reservoir. Using this method only VA and VB need to be controlled. This is problematic because a change in either VA or VB affects both reservoirs. Therefore, extensive fine tuning is required to achieve steady state. This subject no longer has the flow rate gradient line for the reservoirs hence he has a very difficult time stabilizing mass flow. He said that stabilizing mass using the P&ID interface required "too many calculations". This helps to explain why he approached each system goal separately rather than in tandem, as he usually did.

When this subject began to adjust the heaters, he sets H1 to maximum. This is very close to the setting required to achieve steady state. When T1 begins to overshoot the goal area, the subject responds by fine tuning H1. Since no drastic changes were witnessed, AS does not notice the fault. In other words, he does not know enough about the system to detect the fact that his heater is abnormally high to achieve steady state for this set of demands.

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: AV
Interface: P&ID
Initial Conditions: VA1 at half. VA2 at one third. VB2 at maximum. Both heaters at 4. Output flows set to reservoir demands.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Between :44 and 1:25 after the fault the subject slowly increases H1 from 4 to maximum.				
1:39	"Ahhhh..."	I	"I see...this thing (*points to H1*), is screwed up."		
2:00				E	H1 fine tune
2:40				E	H1 fine tune
5:42	*Subject begins singing.*				
6:36			"OK" (*the subject appears to be anticipating demand pair change*)		

Comments: The subject notices soon after the fault that temperature 1 was not what he expected it to be and he diagnoses the problem. He then makes almost no control actions until the end of the trial because the system was already in steady state.

Post-Hoc: AV said that he knew immediately that the heater was broken because the heater did not act as it should. In previous verbal protocols AV said that he always set H1 to whatever the demand D1 was. This may explain how he knew so quickly that there was something wrong: when H1's initial setting of 4 (also the demand, D1) failed to satisfy the temperature goal.

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: TL
Interface: EID
Initial Conditions: VA1, VA2, VB2 open. H1 set to 7 and H2 set to 4. Both reservoirs half full. Outputs set to demands.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	For the first four and a half minutes after the fault ,the subject sets and H1 to many different settings. is off and H1 is set to 5 when he finally indicates verbally that there is a fault. At this point, no water is entering or leaving R1. The system is nowhere near steady state.				
4:50	"This might take half an hour..."				
4:55		I	"Something's weird with one of the heaters, gotta juggle some stuff."		
4:57				E	VO2 fine tunes
5:16				E	VA1 increase to setting 3
5:56				E	VO1 increase to setting 4
6:18				E	VA1 increase to setting 3
6:35				E	VO1 fine tune
7:05				E	VA1 close
7:20				E	VA1 gradually opening
8:22				E	VO1 off
9:00				F	"The strategy here now is to fill reservoir one to 60 or so to keep it for 5 minutes and then to heat it up and then start draining it."

9:18		I	"Because otherwise...the heater isn't putting out enough heat to maintain it at the steady state." *To clarify: He is going to fill up the reservoir with water and heat it to the goal temperature ,then turn off the heater and input water, and open VO1 it let the reservoir drain itself. At this point, the subject is not required to do anything because the water is already heated.*		
10:00				E	VA2, VB2 fine tune
10:54				E	VO1 off
11:23				E	VA1 to 3
11:27				E	VO1 to 4 *The subject maintains a inflow rate of 3, given his setting of 5 he is just able to heat water flowing in at this rate. The subject does not realize that the heater is working at half its setting, he thinks that the heater is only capable of outputting heat at about 2.5.*
11:53				E	VO1, fine tune (*NB: H1 is set to 5 and not touched since detection*)
15:50			*The reservoir is slowly draining since (input - output) is about -1.*		

Comments: TL clearly was not using the information about heat transfer rate. He seemed to be approaching this fault like he would on the P&ID interface. If he looked at the heat transfer on H1, then he would be able to use this information to solve the fault. Instead, he was convinced that the heater output was about 2.5, no matter what the heater setting. He spent most of the trial trying to solve the problem by trial and error by manipulating mass flow rates on R1. He eventually devised an elaborate plan to satisfy goals by filling and heating the water in R1 early and then letting it drain slowly.

Post-Hoc: "There is a defect in the heater: it's set at 5 but only shows a bit over 2. You can see that the output demand is four and 2.5 is not enough to heat a throughput of 4." He said later that he knew from previous experience that a heater setting of 2.5 could heat a flow of 2.5. He did not realize that all he needed to do was set the broken heater to 8 in order to be able to heat a flow of 4. He said that the heat transfer rate graphic was "key" to helping him diagnose and compensate for the fault. He thought that the heater was stuck

at 2.5 because he kept changing his heater setting down as the temperature dropped. He never realized that his heater actions partially contributed to the falling heat transfer rate. The lower he set the heater, the lower the heat transfer rate would fall and hence his heater setting never caught up because the heat transfer rate was always half of the setting (due to the nature of the fault). After he set the heater to 5, he began to modify input flow VA1 for several seconds. This gave the heat transfer rate enough time to stop dropping. It is at this point that he thought the heater was "stuck". He said that he could not get heat to go any higher. He's wrong because he never tried to change the heater setting after the fault, he only modified mass flow rates.

He concluded the post-hoc question period by stating that "if I had the other interface there's no way I could have done it." Unbeknownst to him he did complete an identical trial in much less time on trial #97. However, he finished by saying: "I would have had to use trial and error...actually come to think of it, I do think I've seen this before on the other interface and it took forever."

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: WL
Interface: EID
Initial Conditions: All input valves fully open. H1 full, H2 at half. Both reservoirs half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	At :35 after the fault, he sets H1 to half and then back to full. One minute later he does the same with H2, apparently to observe the effects of that action. At 1:39, he rests the pointer on H1 and moves it slowly along the length of the heater without clicking the mouse. From 2:35 to 3:58 he sets H1 from full to half several times.				
4:14	"Something strange."	O	"When I use the heater (*H1*) and point to 8 it does not go to 8" *The mouse pointer remains on H1 for the remainder of the trial.*		

Comments: From about 35 seconds after the fault, the subject began to focus solely on H1 (he made very few minor adjustments to other components). He spent the first 4 minutes changing the heater from half setting to full and back about five times. It was only after this, at 4:14, that he concluded that something was wrong. He did not have to compensate because he had roughly the correct setting for H1 at start-up as part of his start-up procedure.

Post-Hoc: The first statement that WL made after the trial was: "The only thing is that the first heater doesn't go to full power,...the actual heating rate is about half". He noticed it because temperature was increasing very slowly and later he realized that the heater did not reach its maximum. He dealt with this problem by keeping the heater at maximum and waiting.

WL said that the EID interface was worse than the P&ID because the valve flows are not necessary on the EID interface. He made a similar remark regarding the input and output flow rate connecting line on the reservoirs when he said that it added confusion. He also said that the center graphics

(between the mass and energy reservoirs) may also not be necessary. However he stated that the energy information given by the energy reservoir is "nice"; he liked the line joining input and output energy flows. He said that this energy information leads to a more precise control over temperature.

When asked how he would have done on the P&ID display he said that he would have done the same job. Following this statement, he had trouble remembering if he had heat transfer rate information in the P&ID interface or not. He eventually concluded that he did not have this information. He then said that he would not be able to notice that temperature was being lost. He concluded that he would have to deduce this in the other display by watching the behavior of the temperature with relation to the heater setting.

Trial: 223 (start-up only)
Fault: 1 minute after start of trial, H1's heat transfer rate starts to drops exponentially to half of the setting. (D1=4, D2=12).
Subject: ML
Interface: EID
Initial Conditions: VA1, VB1 set at 2 (half of D1). VA2, VB2 set at 6 (half of D2). VA, VB set at 8 each (half of D1 + D2). H1 set at 4 (D1). H2 set at 4 (D2 / 3). Very low reservoir volumes. Output flow rates set to demands.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:28	"OK...	I	"There's something wrong with this heater (*H1*) apparently."		
:35		I	"Maybe not."		
:56		I	"Yeah, I'd say there is (*a problem with H1*)."		
1:02		I	(*H1*) not working the way it should be."		
1:07		O	"This one 4 for 12 (*H2*), that's fine." *He's checking that H2 is set properly, that is at one third the demand for R2 according to his rules for controlling the system.*		
1:10		O	"4 (*pointing at D1*)		
1:12		I	"so that should be 4 (*he points to H1*)....but it's (*H1*) not responding." *In this sequence of comments, the subject is checking that he has not made a mistake setting H1. According to his set of experiential rules, the setting of H1 should match D1 (a correct inference for normal trials). But in this case H1 is set to 8 or 9 which is about double D1 yet satisfying temperature goals.*		
1:20				D	"How 'bout 8 (*setting for H1*)? Just going to drop it a bit."
1:22				E	H1 decreased to setting of 8
1:37				E	H1 fine tune
1:56		O	"two, 8 + 8, 6..." *He is checking the ratio's of his valves to the demands and fine tuning.*	E	VA1 fine tune
2:12		O	"That's a little low (*R1*)."	E	VA, VB fine tune
2:40				E	VO1 fine tune

3:14				E	H1 fine tune
3:49				E	H1 fine tune
4:13				E	H1 fine tune repeatedly
4:58		O	"It's getting a little low there (*T1*)."	D	"Get it back up."
5:00				E	H1 increase
5:04				E	H1 fine tune
5:18		I	"So it (*H1 setting*) is roughly double." (*Double what he expects*)		
5:29				E	H1 fine tune
5:39			"Must be close to change in demand."		
6:58			"Oh come on, it wasn't that bad was it?"		

Comments: The subject used low reservoir volumes throughout the trial. This allowed him to control the temperature quickly. He noticed the heater fault faster than any other subject. After only four transfer trials, he knew how to effectively use the heat transfer graphic. When his initial settings (based on rules created from experience on earlier trials) failed to achieve the expected temperature on R1, he was able to effectively use the heat transfer graphic to diagnose the problem. Compensation was completed by fine tuning H1.

Post-Hoc: He confidently stated that the heat transfer from H1 was about half of what the setting indicated; "on the other interface you'd have to guess."

TRIAL #224

Summary: transfer fault (valve), see baseline trial #187

Trial: 224
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).

Subject: IS
Interface: P&ID
Initial Conditions: Demand pairs change at 6:27 (one and a half minutes before the fault). VA1 set to 6 and VA2 is set to 2. Reservoirs are about half full. He is approaching steady state.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:36	"Reservoir 1 is behaving (*he is using a decoupled feedwater stream strategy so that the fault on VB does not affect R1*), reservoir 2 (*pause*) Oh,..."	O	"There we go."		
:40					**PB blew up**

Comments: He appeared to notice something was wrong just before the blowup, but was unable to find a source of the problem so appeared to decide to ignore it until he had more information.

Post-Hoc: IS said that he "noticed something wrong with R2 - it was dropping but very slowly so I increased input". He said that he knew it was a valve block because after the blow up he looked at VB and VB2 and they were open yet PB blew up, therefore he deduced that there must have been a block. However, this analysis was done after the blow up. He said "I wouldn't have spotted that because I don't have the flow through readings visible, whereas I'm sure I would have spotted it in the other simulation". He thought that he noticed the symptoms of the fault about one minute before it blew up (the fault occurred 40 seconds before the blow up). He surmised that he may have had a better chance at diagnosing the fault on this interface had there been higher demands. This is because higher demands would have necessitated higher flow rates through VB. Given this alternative situation, the blocking of VB would have stopped a correspondingly higher proportion of water from flowing into the reservoirs. This larger reduction in reservoir input flow would have resulted in a much more visible dropping of the reservoir levels.

Trial: 224
Fault: 8 minutes after start of trial VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: AS
Interface: P&ID
Initial Conditions: Demand pairs had not changed yet. All secondary valves almost fully open. Temperature is at steady state. Reservoirs are half full. VA and VB are at 6 (reflecting the demand settings).

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:39					PB blows up

Comments: AS did not notice the fault at all.

Post-Hoc: After the trial aborted, he looked at the screen for a while and then reasoned that VB must have been broken. He said that there was no way that he could tell because he did not have an indicator. Since this was the last trial, he complained: "Why did it have to end this way?". He wanted to know why his last trial had to end with a blow up. He wanted to end on a more positive note.

He remarked that the "P&ID interface is very bad". He said that he missed "everything" from the EID interface. He said that he missed the indicators, flow rate descriptions, gradients etc. On the P&ID interface, he complained that he must spend too much time focusing on water levels in the reservoirs to see what direction they are going.

Trial: 224
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: AV
Interface: P&ID
Initial Conditions: Demand pairs change at 5:55 (two minutes before the fault). By 6:00 he has both reservoirs full and heated to goal temperatures. VA1 is set to 7 and VA2 is closed. He has also turned off PB because there is enough water in R2 to satisfy demand for 5 minutes (until shut-down).

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	He explains his strategy of filling the reservoirs and heating them to goal temperatures and then draining them. This way the heaters are fully cooled by shut-down.				

Comments: AV performed this trial almost identically to the baseline trial. He sets up the reservoirs so that R2 was heated to goal temperature and drained itself for the remainder of the trial. As discussed for trial 187, AV missed the fault because he was not using any of the components which were affected by the fault.

Post-Hoc: None.

Trial: 224
Fault: 8 minutes after start of trial, VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: TL
Interface: EID
Initial Conditions: Demand pairs change at 5:46 (over two minutes before the fault). Like his baseline trial (187) and similar to AV he turns off PB at 6:00 and lets R2 drain itself. He only focuses on R1 which is about half full with VA1 supplying water. All demands are being met.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	Well before the fault he has changed his configuration to using just the top feedwater stream. There is enough water in R2 to satisfy demand until shut down. He can now ignore this reservoir and let it drain itself. He did explain in other analyses that this was the strategy he used for anticipating shut down.				

Comments: As with baseline trial 187, TL configured the system before the fault in such a way that the fault did not affect the components that he was using.

Post-Hoc: TL had no comments with respect to the fault (which is understandable, since he did not experience it). However, he did have comments about the EID interface. He said that "EID is much better". He liked the extra information that was given in this interface. He found the exact output of each heater and each valve beneficial. Of secondary importance was being able to see how much energy was going in and out of the reservoir - "it takes the guess work out". However, he emphasized that this information was not as important as the components' functional information. The single most important benefit he found was the heat transfer rate on the heater. He noted that this feature "illustrates the lag". If he could change the interface he said that he would unclutter it by getting rid of many of the mass/energy gradient lines which he perceived to be unnecessary. When first using the interface, these lines were overwhelming until "your brain gets used to it". Finally, he found the reservoir graphics easier because they were bigger (here he is referring to the extra energy information coupled with the reservoir). This graphic makes it easier to see changes, he said. "The lines

often catch my eye". TL also liked the colors. Even though he praised the EID interface, TL did not appear to be exploiting the features of the display which he found beneficial.

Trial: 224
Fault: 8 minutes after start of trial VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: WL
Interface: EID
Initial Conditions: Demand pairs changed at 6:54 (one minute before the fault). VA1 and VB1 were set to 5, and VA2 and VB2 were set to 1. Both reservoirs half full.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
	When fault happened WL was focusing on H1. Just before PB blew up, he turned H1 completely off. This was likely because the temperature of R1 was increasing due to the reduced input water flow from VB1 (the same effect occurred on R2 but WL did not notice it).				
:41					**PB blows up**

Comments: WL performed this trial much in the same way he did the baseline trial. He appeared to have no idea what caused PB to blow up. This is possibly because he did not appear to use any of the functional information present in this interface. In fact, in the post-hoc discussion he said that he did not think that the extra information was important.

Post-Hoc: WL stated that he noticed that temperature was increasing when the volume on R1 was dropping quickly. After a couple of minutes of thinking and reasoning aloud after the trial ended, he still could not figure out why PB blew up. He did not appear to use the functional information present in this interface (EID). From his actions and his comments, it seemed that WL was operating DURESS II by only looking at the cues he normally used on the P&ID interface while ignoring all the others. When asked after the trial what he looked at when he controlled the system using the EID interface he said: "everything I look at is the same (*as P&ID*) except I look at the energy".

When asked how he would do on the other interface, he said that he could only notice the fault by the reservoir level dropping. After seven minutes of

thinking and explaining what he did, WL finally conceded that the functional information for the valves would be useful (this is opposite to his comment on trial 223 about the valve flow meters). "You're right, in this case (*trial 224 where there is a valve block*) this (*flow rates*) provides some useful information about performance of your system. Isn't that strange...(*pauses*) that (*VB blocking*) is an unusual case, that is rare, it's unnatural. On a real system like this it doesn't happen."

Ironically WL finishes the unusually long post-hoc discussion with the statement: "So totally, I will say this interface gives you more complete information - almost anything. Certainly you can deal with any situation better than the old interface".

Trial: 224
Fault: 8 minutes after start of trial VB becomes blocked. Flow rate through valve begins to drop exponentially to zero. (D1=6, D2=7 change to D1=7, D2=2).
Subject: ML
Interface: EID
Initial Conditions: Demand pairs change at 6:58 (one minute before the fault). and VB1 are set to 7 (D1 setting) VA1 and VA2 and VB2 are set to 2 (D2 setting). This setup is consistent with his "ratio" method. Reservoir levels are less than half full. H1 set to 7 and H2 set very low.

Time after fault (min:sec)	Detection Activation		Diagnosis [O]bservation [I]dentification		Compensation [D]efine Task [F]ormulate a procedure [E]xecute [I]nterpret*
:14	"OK..."	O	"Something's going wrong"		
:16				E	VA2 increase
:21		O	"Is it this one? Oh, it's this one (*VA*)."		
:23				E	PB off, VA set to maximum
:30				D	"9 (*VA*), 7 (*VA1*), 2 (*VA2*)"
				E	VA to 9, VA1 to 7, VA2 to 2 *He reconfigures the system in a few seconds.*
:48				E	VA fine tune
				E	*Subject fine turns H1 and H2 intermittently throughout the remainder of the trial.*

Comments: ML quickly detected the fault. He noticed the R1 level dropping and then quickly noticed that the flowrate on VB was zero, even though VB was open. Once he diagnosed this as the problem, he reconfigured the system in a few seconds and completed the trial with very few modifications to the component settings. This trial was a marked contrast to ML's baseline trial, where he only detected the fault and failed to complete the trial. It was surprising that ML performed the best of all subjects on the transfer trials, yet he was by most measures one of the worst subjects on the trials where he had to use the P&ID interface.

Post-Hoc: ML's first statement after the trial was: "Something went wrong with the bottom valve (*VB*), the main valve, because nothing was flowing through... or something was wrong with the pump (*given the information in the display either of these scenarios could have been in effect*) or what have you, but there was nothing flowing through. I assume that it was the

primary valve rather than the pump". ML remarked that this trial was "no problem" to finish.

When asked if he thought that the EID interface was better he exclaimed "Oh, God yeah. You have more information, you know what's going on, you can see that there is nothing flowing through, therefore there is something wrong with that. You don't have to guess which one is going wrong - you know it's this one (*VB*) so you just turn it off. With temperature, like in the past trial (*223*) you can see that it is only flowing at about half, so you can double it (*the heater setting*) to get the flow that you're looking for". He continued at length about how much easier the EID interface is for pinpointing problems. This subject clearly preferred the EID interface.