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Appendix A.1 Data Collection Forms and Questionnaires

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A.1.1 Demographic Form

Name:____

Age:________Gender:________Major:______________________GPA:__________

Home Phone:________________Office Phone:______________Email Address:_____________

YES NO I am familiar with the concept of life-cycle costs
YES NO I am familiar with the concept of engineering design life-cycle
YES NO I am familiar with the concept of project management

Number of engineering design projects you have worked on ___________

In the space below mark out times that you are definitely **not** available to participate in a 3-4 hour experiment.

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
8-9 am							
9-10 am							
10-11am							
11 am-12 pm							
12-1 pm							
1-2 pm							
2-3 pm							
3-4 pm							
4-5 pm							
5-6 pm							
6-7 pm							
7-8 pm							
8-9 pm							

Please write down my name and how to contact me so you can call me if there is a problem:

Paige Smith
(301) 405-3931 (Work) (301) 681-5809 (Home)
pesmith@deans.umd.edu

A.1.2 Planning Form

1. The project management tools were easy to use.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

2. The project management tools improved the efficiency of planning

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. The project management tools improved the effectiveness of planning

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. The project management tools improved the productivity of planning

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

5. Overall I was extremely satisfied with the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. There is no doubt that we will be able to complete the project on schedule and on budget.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

7. The plan that was developed was the best plan we could have created.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

This questionnaire was only be administered to participants with project support.

A.1.3 Conceptual Design Form

1. The project management tools were easy to use.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

2. The project management tools improved the efficiency of implementing the plan for conceptual design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. The project management tools improved the effectiveness of implementing the plan for conceptual design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. We were more productive during conceptual design because of the project management tools we used.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

5. Overall I was extremely satisfied with the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. There is no doubt that we will be able to develop a good system using one of the ideas from the list of concepts.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

Questions 1-5 were only given to participants with project support.

A.1.4 Preliminary Design Form

1. The project management tools were easy to use.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

2. The project management tools improved the efficiency of implementing the plan for preliminary design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. The project management tools improved the effectiveness of implementing the plan for preliminary design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. We were more productive during preliminary design because of the project management tools we used.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

5. Overall I was extremely satisfied with the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. There is no doubt the concept we selected will result in a system that meets the performance requirements.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

Questions 1-5 were only given to participants with project management support.

A.1.5 Detailed Design Form

1. The project management tools were easy to use.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

2. The project management tools improved the efficiency of implementing the plan for detailed design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. The project management tools improved the effectiveness of implementing the plan for detailed design.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. We were more productive during detailed design because of the project management tools we used.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

5. Overall I was extremely satisfied with the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. There is no doubt the concept we selected will result in a system that meets the performance requirements.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

Questions 1-5 was only given to participants with project support.

A.1.6 Post-experiment Form

1. I/we designed the best system within my/our ability.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

2. I liked the final system that I/we built.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. I was very satisfied with the project management tools that I used during the design process.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. I/we was able to meet or exceed the goal I/we defined at the beginning today's project.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

5. We were more productive during the design process because of the project management tools we used.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. The project management tools were easy to use.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

7. We were able to stay on schedule as well as we did because of the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

8. We were able to stay on budget as well as we did because of the project management tools.

1	2	3	4	5
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

Questions 3, 5, 6, 7, and 8 were only given to participants with project support.

Appendix A.2 Engineering Design Project

THE "MISSION POSSIBLE" CASE (for treatments with project support, adapted from Meredith, 1997)

Your company is in competition for a secret government contract to design, build, and test a transportation system. This system will be used to move a spherical container of valuable material from behind enemy lines to friendly territory. The enemy has erected a large barricade across the only road out.

In order for your company to work on this project without attracting local attention, your team will create a prototype using toys. This prototype, if successful, will be used to secure funding to complete the actual system.

The requirements have been scaled from the real situation to requirements for the prototype system. The prototype system must move a ping-pong ball (i.e., spherical container) from a starting point (i.e., current location) to a finish line (i.e., friendly territory) as shown in Figure 1. You may not touch the ball or the hurdle (i.e., barricade) at any time. The ball may be moved over or around the hurdle. You may not use human energy to move the ball. The ball rests on a LEGO piece (5/8" x 5/8" x 3/8") at the starting line.

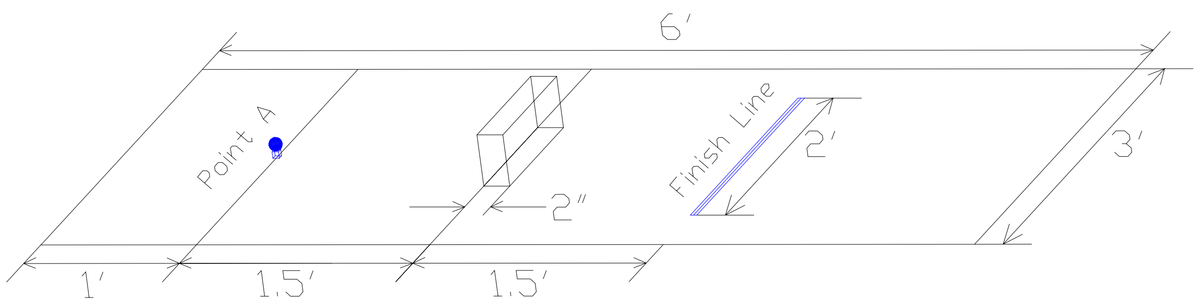


Figure 1 Test site layout

You must build your prototypes with LEGOS and the following materials: a roll of masking tape, rubber bands, a 4" x 7" piece of cardboard, paper and scissors.

Your team's design will be evaluated on several criteria such as how long the design process takes and how easy it is to build (producability). Your team's design documentation and the costs associated with creating the system will be evaluated. However, the most important criterion is if the system meets the performance specification (in other words, does the system move the ball to the finish line).

Each one of your team members has been assigned to a function – either design, manufacturing, or purchasing. Each function has goals that will be given to you later during the experiment that you should attempt to achieve. Individual performance will be a function of how well you achieve your functional goals.

It is possible that the requirements for the toy system do not exactly simulate the requirements of the actual system. Therefore, your design should be as robust as possible. This means the design should still be capable of meeting the performance specifications given minor changes in the requirements. For example, our intelligence forces may be slightly incorrect in the exact location or height of the barrier, or the weight or size of the container.

Your team does not have an unlimited amount of time or money to complete this project. You have 55 minutes to plan your project and 2 hours to execute your plan. The government has offered an incentive bonus for early completion of the project. Your team has been allocated $685 for this project.

The overall approach to the experiment is based on a design project's lifecycle. First you will prepare a scoping document. Then you will prepare a plan and budget. There are 3 design activities (conceptual design, preliminary detail design, and detailed design) and a testing activity that you must plan and execute. In your schedule, you must include a review meeting at the end of each design phase to review the required deliverables. You must hold a status meeting every 30 minutes during implementation. The main purpose of conceptual design is to generate ideas for potential systems. In preliminary design you will explore two feasible solutions and then select the idea you think has the highest chance for success. During detailed design, you will create manufacturing instructions in the form of detailing drawings and textual directions and descriptions. During testing, you will build a prototype and test it to see if it meets the performance specifications.

The following are the specific deliverables from each phase:

Planning

- Scoping document
    - Problem/Opportunity
    - Goal
    - Objectives
    - Measures of success
    - Risks and threats
- Work Breakdown Structure
    - Level 1 activities: conceptual design, preliminary design, detailed design, testing
    - Need a *minimum* of 3 sub-activities under each level 1 activity.
    - Assign primary responsibility
    - Estimate duration
    - Identify task dependencies
- Gantt Chart
- Resource allocation/budget

Conceptual Design

- Overall goal of the design project.
- List of design criteria - includes performance parameters, system requirements, and/or operational requirements.
- List of ideas for system (as many as you can think of). Do NOT eliminate any ideas during conceptual design.

Preliminary Design

- Reduce list of ideas to 2 potential concepts.
    - High-level sketch of each concept. Include overall dimensions and the general shape.
    - Brief written description of each concept.
- Tradeoff analysis
    - Strengths and weaknesses of each system
    - Lifecycle cost estimate for each system
    - Create rough prototype of each alternative
- Select single concept

Detailed Design

- Documentation justifying the system that was selected
- Detailed drawings (dimensioned)
    - two views of the system
    - at least one-view of subsystem that interacts initially with the ball
- Textual instructions on how to assemble the system
- A bill of material

Building & Testing

- The manufacturer should build the new prototype from scratch according to the instructions. Design errors need to be recorded and explained, and the lifecycle cost for the system needs to be calculated.
- The system will be tested three times for reliability and accuracy.

Status Reports

- Record of % complete and track on Gantt chart.
- Update Actual column in budget with amount spent (include only labor).
- Calculate CPI and SPI.

Between the design tasks you will complete several of questionnaires. These questionnaires do not count as part of your 2-hour design time. These questionnaires are very important because they are gathering information about your perceptions through out the planning and design process.

Good luck, the Mission Possible force is counting on you. Remember, you may not discuss this top-secret project with anyone outside of this room.

Note for individuals any reference to team was removed and the budget was changed to $445.

THE “MISSION POSSIBLE” CASE (for treatments without project support, adapted from Meredith, 1997)

Your company is in competition for a secret government contract to design, build, and test a transportation system. This system will be used to move a spherical container of valuable material from behind enemy lines to friendly territory. The enemy has erected a large barricade across the only road out.

In order for your company to work on this project without attracting local attention, your team will create a prototype using toys. This prototype, if successful, will be used to secure funding to complete the actual system.

The requirements have been scaled from the real situation to requirements for the prototype system. The prototype system must move a ping-pong ball (i.e., spherical container) from a starting point (i.e., current location) to a finish line (i.e., friendly territory) as shown in Figure 1. You may not touch the ball or the hurdle (i.e., barricade) at any time. The ball may be moved over or around the hurdle. You may not use human energy to move the ball. The ball rests on a LEGO piece (5/8” x 5/8” x 3/8”) at the starting line.

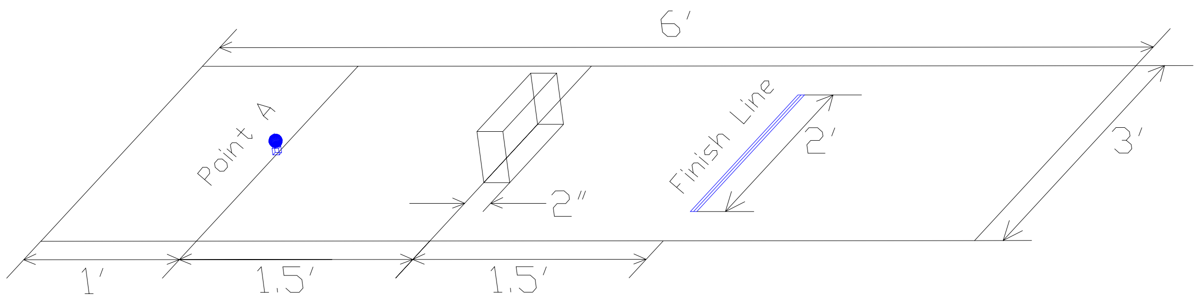


Figure 1 Test site layout

Your team must build your prototypes with LEGOS and the following materials: a roll of masking tape, rubber bands, a 4” x 7” piece of cardboard, paper and, scissors.

Your team’s design will be evaluated on several criteria such as how long the design process takes and how easy it is to build (producability). Your team’s design documentation and the costs associated with creating the system will be also evaluated. However, the most important criterion is if the system meets the performance specification (in other words, does the system move the ball to the finish line).

It is possible that the requirements for the toy system do not exactly simulate the requirements of the actual system. Therefore, your design should be as robust as possible. This means the design should still be capable of meeting the performance specifications given minor changes in the requirements. For example, our intelligence forces may be slightly incorrect in the exact location or height of the barrier, or the weight or size of the container.

Your team does not have an unlimited amount of time or money to complete this task. You have 2 hours to complete this project. The government has offered an incentive bonus for early completion of the project. Your team has been allocated $685 for this project.

Each one of your team members has been assigned to a function – either design, manufacturing, or purchasing. Each function has goals that will be given to you later during the experiment that you should attempt to achieve. Individual performance will be a function of how well you achieve your functional goals.

The overall approach to the experiment is based on a design project's lifecycle. There are 3 design activities (conceptual design, preliminary detail design, and detailed design) and a testing activity that you must complete. The main purpose of conceptual design is to generate ideas for potential systems. In preliminary design you will explore two feasible solutions and then select the idea you think has the highest chance for success. During detailed design, you will create manufacturing instructions in the form of detailing drawings and textual directions and descriptions. During testing, you will build a prototype and test it to see if it meets the performance specifications.

The following are the specific deliverables from each phase:

<u>Conceptual Design</u>

- Overall goal of the design project.
- List of design criteria - includes performance parameters, system requirements, and/or operational requirements.
- List of ideas for system (as many as you can think of). Do NOT eliminate any ideas during conceptual design.

<u>Preliminary Design</u>

- Reduce list of ideas to 2 potential concepts.
    - High-level sketch of each concept. Include overall dimensions and the general shape.
    - Brief written description of each concept.
- Tradeoff analysis
    - Strengths and weaknesses of each system
    - Lifecycle cost estimate for each system
    - Create rough prototype of each alternative
- Select single concept

<u>Detailed Design</u>

- Documentation justifying the system that was selected
- Detailed drawings (dimensioned)
    - two views of the system
    - at least one-view of subsystem that interacts initially with the ball
- Textual instructions on how to assemble the system
- A bill of material

<u>Building & Testing</u>

- The manufacturer should build the new prototype from scratch according to the instructions. Design errors need to be recorded and explained, and the lifecycle cost for the system needs to be calculated.
- The system will be tested three times for reliability and accuracy.

Between the design tasks you will complete several of questionnaires. These questionnaires do not count as part of your design time. These questionnaires are very important because they are gathering information about your perceptions through out the design process.

Good luck, the Mission Possible force is counting on you! Remember, you may not discuss this top-secret project with anyone outside of this room.

Note for individuals any reference to team was removed and the budget was changed to $445.

Appendix A.3 Script

This appendix contains general instructions for the task: Mission Possible (adapted from Meredith, 1997).

A.3.1 Pre-Experiment Preparation

Select the first 72 engineering students who are 18 years of age or older that volunteer to be in this study. Randomly assign these students cells.

Notify the students that have been assigned to project management support conditions to schedule the training session. Based on the schedules of the participants, schedule the training session: 1 hour for unsupported, 3 hours for manual and an additional 45 minutes for automated. During the training session, participants will complete the demographic form and informed consent form. One day prior to each training and trial, email and phone the student to confirm that they will be able to participate.

A.3.2 Training

A.3.2.1 Greeting

Before we being our training, you need to complete an informed consent and demographic information form. When you return for the experiment I will give you a copy of the last page of the informed consent form. Please feel free to contact me at any time regarding this experiment. Please read and sign the Consent Form.

Wait while participant(s) is completing the Consent Form.

Thank you. Before we get started, let me remind you that it is very important that you do not discuss today's training or the experiment with anyone outside of this room. If you do, you might accidentally give away information, which will give a competing team/individual an unfair advantage. Do you have any questions before we begin?

A.3.2.2 Tutorials

Today we will have several brief training exercises. We will start with project management training (*if in the supported condition*). Then we will move on to LEGOS, detailed drawings, LEGOS assembly, and lifecycle cost calculations.

Handout the Project Management tutorial to all participants (includes figures and bill of material.) Walk the participants through the project management slides and exercises. Have the participants complete the exercises and ensure they have the concepts right before moving onto the next concept. If the exercises are not being completed as they should discuss the problem and help them work though the problem. At the end, administer the term quiz.

In groups the following tutorials will be cycled through all of the groups. For the individuals the tutorials will be administered in the following order: LEGOS, detailed drawings, manufacturing with a three view drawing, and lifecycle costs.

Handout the LEGOS tutorial to all participants (includes figures and bill of material).

At this time, read the information on LEGOS. Please ask me questions at any time during this tutorial. Feel free to use the LEGO pieces as you read through the tutorial to demonstrate connections.

Wait while participants read through the LEGOS manual

Any questions? Now, we will complete the exercises to make sure that you can create a detailed drawing, interpret a three-view drawing to assemble LEGOS, and calculate lifecycle costs.

These are training exercises so if you have any problems, please let me know and we can fix them.

Distribute the detailed drawing tutorial first.

Please read through the detail drawing tutorial and complete the associated exercise. You will be timed. Please let me know when you think you have correctly produced the drawing. Don't hesitate to ask me questions while you work on this tutorial. You may begin.

Time the tutorial. Review the drawing to make sure that it is correct. Repeat the exercise until the drawing is correct. Once a correct design is drawn, record the stop time. In groups, after the first person is started on this tutorial, give the next person the LEGO Assembly Tutorial.

You will work on assembling a LEGO system by interpreting a three-view drawing. I'm going to time you to determine the how long it takes you to assemble the system. Here is a bag of LEGO pieces that you can use to assemble the car shown in your drawing. Please let me know when you have an assembled car. Don't hesitate to ask me questions while you work on this tutorial. You may begin.

Record the start time for assembly training. Verify that the car is assembled correctly. The training session is not over until the car is assembled correctly. Once the car is correctly assembled, record the stop time in the log. Once the manufacturing tutorial is started, give the lifecycle cost tutorial to the next person.

While the other exercises are in progress, I would like you to complete a training exercise on the calculation of lifecycle costs. Please read through the tutorial and complete the associated exercise. You will be timed, so please let me know when you have completed this exercise. You may begin.

Record the start time. Make sure the lifecycle costs have been correctly calculated. Then record the stop time. When one person has completed their tutorial have them start the next available tutorial. If there is waiting time, have them review the LEGOS tutorial again. Wait until everyone is done with their tutorials.

Thank you for completing the training for my experiment. Don't forget you are scheduled to meet ______________________ for your trial. I will send you an email and phone reminder. If you have any questions or concerns between now and your meeting date, please contact me.

A.3.3 Trial

Have extra informed consent forms and demographic questionnaires available in case a participant has not completed them (non-project management conditions only).

A.3.3.1 Greeting

Before we being the experiment, I will give you a copy of the last page of the informed consent form that you signed. Please feel free to contact me at any time regarding this experiment.

Before we get started, let me remind you that it is very important that you do not discuss today's experiment with anyone outside of this room. If you do, you might accidentally give away information, which will give a competing team/individual an unfair advantage. Do you have any questions before we begin?

If it is a team condition, assign participants to functions: design, manufacturing, and support.

To Groups: Your team members have been randomly assigned to the designing, manufacturing, and purchasing functions. Please wear your functional nametag in a conspicuous place. The designer is responsible for all of the drawings for your system. The manufacturer is ultimately responsible for assembling the system. The purchaser is responsible for keeping track of the lifecycle costs.

To Individuals: You are responsible for all of the aspects of design. This includes creating drawings, assembling the system, keeping track of the life-cycle costs, and providing documentation when required.

During the training session, you received training for these roles. Do you have any questions about your role?

A.3.3.2 Explanation of the Design Task

Note that items in [] are only to be read to the group treatment.

Now, you are receiving a copy of the Mission Possible Case, which includes a summary of the deliverables for each design phase.

Distribute the Mission Possible Case (Appendix A.2).

Please read through the description and deliverables.

Wait while participant(s) read the case. Go over to the test area.

Let's review the problem. You are [*your team is*] going to design a system to move this ping-pong ball from the starting point to finish line. The ping-pong ball may go over the hurdle or around the hurdle, but please do not try to go through or under the hurdle!

The ping-pong ball can roll across or fly over the finish line. But it must cross the line. *Point to demonstrate these areas*.

You may not use the wall as part of your system. If your solution requires a wall, build it out of LEGOS or one of the other materials provided to you.

You may not lift the ball from its starting point and put it on your system. The ball will be sitting on the LEGO piece, as it currently is, at the beginning of the testing.

You can hold your system in tension, or use some other form of potential energy. Or if you decide to use the motor, you can turn on the motor. However, you cannot interact with your system in any other way during testing.

Do you have any questions so far?

Answer any questions.

Before we begin please read through your functional goals for conceptual design, preliminary design, and detailed design. You will be evaluated on your ability to achieve these goals.

Distribute the goals of the design organization to the respective members.

Are there any questions about what your goals are?

Answer any questions. Follow specific instructions depending on the treatment.

A.3.3.3 Conditions without Project Planning

You need to log the time it takes you to complete this project. [*This task is part of the purchaser's task*.] You have 2 hours and $445 [*groups*: $650] to complete this design project. The time constraint does not include the questionnaires you complete at the end of each phase.

Conceptual Design

We are about to start the conceptual design phase. The main purpose of conceptual design is to determine as many feasible approaches as possible to satisfy the problem.

For this design phase, [*as a group*] determine the overall goal, the design criteria, and a list of potential concepts. Please keep a written record of the work and do not destroy any work done during Conceptual Design. Refer to the project description to help remind you of what is required in this phase.

Please use the Conceptual Design Form to record your ideas. Once you have a goal, create a written version of this goal on the form. The next step is to determine and document the design criteria. This includes performance parameters, system requirements, and/or operational requirements for your system. When you have finished determining what your design criteria are [*and have agreement amongst your group members,*] please create a written listing of these requirements on the form provided. The last part of conceptual design is to generate as many ideas for the system as you can. Since you are generating ideas, do NOT eliminate any ideas at this point. Keep a written list of the ideas. Keep trying to determine ideas until you can't come up with anything new.

Are there any questions? You may now begin. Please record the start time in the log. When you have your goal, design criteria, and list of potential solutions, please let me know.

Wait until they tell you they are finished:

Please record the stop time in the log. We have now concluded the conceptual design phase.

Record stop time on log sheet.

At this time I have a several forms for you to complete.

Distribute in the following order: NASA-TLX, Team workload scale, Job Satisfaction, and conceptual design form. Wait until they have finished each one, then collect form and distributed the next form. Ensure the form has participant's functional position on it.

Preliminary Design

Now we are about begin the Preliminary Design phase. Don't forget to keep an eye on the clock. You need to make sure you can finish this project in the next ___________minutes.

During preliminary design you [*your group*] will narrow down the list of potential concepts to two potential solutions. For each potential solution, create a high level sketch to show the general shapes and dimensions and provide a brief textual description of the system. Then, you will conduct a trade-off analysis of the two systems. This includes determining the strengths and weaknesses, developing a very rough prototype for each concept, and estimating lifecycle cost. The final step is to select a concept to be refined during detailed design.

Remember the time constraint and don't spend too long on the prototyping. You just want to get a rough idea for each concept…enough of to give you an idea of each concept and help you make a decision -- not to develop two fully completed model.

Are there any questions about what you are supposed to do? Please review your functional goals.

Answer questions.

At this time you may begin preliminary design. Please record the start time in the log. Don't forget to refer to your project description for the requirements of this phase. Let me know when you have finished.

Enter start time in log. Wait until they have finished.

Please record the stop time in the log. You have now concluded preliminary design.

Enter stop time in log sheet.

At this time I have several forms for you to complete.

Distribute in the following order: NASA-TLX, Team workload scale, Job Satisfaction, and preliminary design. Wait until they have finished each one, then collect form and distributed the next form. Ensure the form has the participant's functional position on it.

Detailed Design

Now we will begin detailed design. Again let me remind you to work quickly. You only have _____________ minutes to finish this project.

The purpose of detailed design is to convert the concept you selected during preliminary design into a design that can be built by others.

Your deliverables from this stage are: detailed drawings of two views of the system, a detailed drawing of the subsystem that interacts initially with the ball; explicit instructions on how to assemble the system; and a bill of material. You should dimension all drawings. During this phase you may not work on the prototype you built previously. You can view the prototype and you can interact with LEGO parts to see how the parts connect. Do you have any questions?

Answer any questions

Please review for functional goals for Detailed Design. (*pause*) You may begin. Please record the start time in the log. Let me know when you have completed this task.

Enter the start time in the log. Wait while they work. Wait until finished

Please record the stop time in the log. We have now concluded the detailed design phase.

At this time I have several forms for you to complete.

Distribute in the following order: NASA-TLX, Team workload scale, Job Satisfaction, and detailed design. Wait until they have finished each one, then collect form and distributed the next form. Ensure the form has participant's functional position on it.

Testing

The team will build and test the final design three times for reliability and accuracy (same as during preliminary design) and three times for robustness. All results are recorded in the Log. The final lifecycle cost is calculated again after the testing is complete.

You have completed the formal design process. However, we need to see if your final prototype will meet the requirements. Following the instructions, [*the manufacturer needs to*] build the system. You will be timed. Only follow what is explicitly given to you in the drawings and instructions. [*The designer needs to*] Record design errors as they occur. If there are manufacturing are errors, point them out so they can be corrected and then make a note of it in the error report. You may begin building the system. Please record the start time in the log. As soon as the system is built, record the stop time.

Record the start time on the log.

Wait until the prototype is ready then make sure they entered the stop time:

Now we will test your system. Please record the start time. Set up your system and let me know when you are ready. We will run the test three times.

Complete the series of tests. Record results as they occur. If at least one of the ping pong balls passes the barrier test for robustness.

Now we will test for robustness. We will run the exact same set of tests as before, but now we will use a golf ball in place of the ping-pong ball. Please set up your system and let me know when you are ready.

Give participant(s) the golf ball. Record the results as they occur. Enter the stop time in the log after the last test is complete.

Please record the stop time in the log. *To the purchaser:* Now you have all of the information needed to calculate the lifecycle cost for the system. Please do so now and we will be finished.

Wait until costs are calculated.

At this time I have several forms for you to complete. While you complete this set of questionnaires, please reflect back over your entire experience here today and respond based on your entire experience.

Distribute in the following order: NASA-TLX, Team workload, Satisfaction, and post-experiment form. Wait until they have finished each one, then collect form and distributed the next form. Ensure the form has appropriate label and the participant's functional position on it (if it is a group condition).

Thank you very much for participating in this experiment. I will let you know how your system ranked relative to the other systems once all of the trials are complete. Remember not to reveal any information about what you did today until after you have received the system rankings. If your system turns out to be the winner, I will be in contact with you to determine how to deliver your award. If your phone number or email changes before I contact you, please be sure to let me know.

A.3.3.4 Conditions with Project Planning

Information that appears in italics and in square brackets is to be read to groups. Information in {} is to be read to those with automated support.

You have 55 minutes to plan your design activities and 2 hours to implement your plan. You also have a cost constraint of $445 [*groups*: $650]. Note that this includes all labor, material, and maintenance costs [technology if that treatment], but does not include your labor time during planning.

Planning

We are about to begin planning the design project. For this phase, [*as a group*], you need to prepare a scoping document – you will use MS word to create your scoping document. Then you [*your group*] will need to determine what design activities you must complete in order to satisfy the mission possible project. A WBS has already been entered into MS Project. Feel free to alter it in any way you desire. However, you must include the first level activities and at least 3 level two activities.

During conceptual design you will need to determine the design criteria and develop a list of as many potential solutions as possible. During preliminary design, you will select two of the most feasible ideas and create high level sketches and textual descriptions for the two ideas. Then you will conduct a tradeoff analysis. Included in your tradeoff analysis should be the strengths/weaknesses of each system, a lifecycle cost estimate for each system. Then you should build rough prototypes to get a better grasp of each concept. Be careful with your time it is easy to spend too much time trying to perfect a prototype. The purpose of prototyping during preliminary design is to help you decide which system to choose – not to develop a full blown detailed model. By the end of preliminary design you should select a single concept to be further developed during detailed design.

The purpose of detailed design is to convert the concept you selected during preliminary design into a design that can be built by others. A measure of your team's performance is how accurate and complete your instructions are. If the manufacturer makes mistakes, it will count against your team's performance, so be as clear as you can be. Your outputs will include a 2-view detailed drawing of the overall system, a one-view drawing of the subsystem that interacts with the payload, explicit written directions on how to assemble the system, and a bill of material. You may also use sketches to demonstrate connections if you want to.

[*Groups*: After detailed design is complete, the manufacturer will build the system from scratch according to the drawings and instructions and the designer will observe and keep a record of the errors that occur. Do not make assumptions while building…if you have questions ask the designer. The manufacturer will be timed on how long it takes to build the system. Then the system will be tested three times for reliability and accuracy. Once testing is complete the lifecycle cost needs to be determined and you will be finished. Are there any questions about what is required of you?]

[*Individuals*: After detailed design is complete, you will build the system from scratch according to the drawings and instructions. Errors that are made during manufacturing need to be recorded. Do not make assumptions while building. You will be timed on how long it takes to build the system. Then the system will be tested three times for reliability and accuracy. Once testing is complete the lifecycle cost will be determined and you will be finished. Are there any questions about what is required of you?]

Answer questions.

To help you plan and schedule activities, you will be modifying a work breakdown structure that includes the following high-level activities: conceptual design, preliminary design, detailed design, and testing. Don't forget to estimate durations.

After you have a WBS, you will schedule the activities using a Gantt chart. Then, you will need to allocate resources to each of the activities in order to create your baseline budget.

{Please use Microsoft Project to help you plan your project.} Please use the forms provided to you to help guide you through the planning process. Please document all of your work. {Please save any work you do on the computer.}

Are there any questions about what you should be planning?

Remind them of the time 30 minutes through out the planning process.

Please review the background information on your [*group's*] mission. [*As a group*] Develop a scoping document for the design project. {Use MS Word to document your scoping document. Once you have a [*group*] goal, save and print it out. /You can use the paper and pens to help you record your ideas. Once you have a final version recorded, let me know.} Let me know when you have a scooping document. You may begin. Please record the start time.

Wait until they have a scoping document.

The next step is to plan the project. Modify the work breakdown structure to indicate all of the activities and subactivities that must be completed in order for you [your team] to complete this project. The level-one activities must include conceptual design, preliminary design, detailed design, and testing.

Don't forget that part of creating the WBS is estimating the time durations for each activity. Be sure to be as realistic in the time estimation as possible. Part of your evaluation is based on how well you are able to remain on schedule. The next step is to schedule the activities you identified in your WBS using a Gantt chart. Also schedule status report meetings every 30 minutes and review meetings at the end of each design phase. Let me know when you are finished.

Wait until they have a Gantt chart. If it is an automated condition, make sure they have saved it.

Now we need to figure out the best way to use the resources we have been allocated. Just allocate the labor expenses and not material or equipment costs. Each member's pay rate is $1/minute (or $60/hour). To help you plan, you have [the purchasing representative has] a bill of materials for the parts you can use to create the system. You want to try to estimate your costs as closely as possible. You are being evaluated on how closely you adhere to your cost estimate. Please use the form provided to report your budget. Let me know when you are finished.

Wait while they assign resources and determine a baseline budget.

Do you [Does anyone] want to change or add to any work completed thus far? If you decide to make changes to anything you will need to up-date your documents. Let me know when you are finished and we will move on.

Wait while they discuss. Once they say they are in agreement, print out any changed documents and replace the old documents.

{Please save the baseline (*Tool, tracking, save baseline*)}. Please record the stop time in the log. We have now concluded the planning phase. At this time I have several forms for you to complete. I will distribute them one at a time.

Distribute in the following order: NASA-TLX, Team scale, Job Satisfaction, and Planning Form. Wait until they have finished each one, then collect form and distributed the next form.

Implementation

During implementation make sure the participants hold status report meetings every 30 minutes.

Now you will implement your plan. Don't forget to adhere to your status meetings that have been scheduled every 30 minutes. During your status reports you will need to update your progress on your Gantt chart and evaluate your progress. These updates are very important, although they might seem tedious. Tracking performance regularly will help us to identify problems in our budget and schedule early so that we can come up with solutions in a timely manner. Let me remind you that you will need to update your current date and status date (Project – Project information) before updating your percent complete. All of the information you should need can be viewed from the Gantt Chart View.

Don't forget about your functional goals for conceptual design. Record the start time in the log under conceptual design. You may begin. Let me know when you have finished conceptual design.

Wait until they tell you they are finished with conceptual design.

Please record the stop time. You have now completed conceptual design. At this time I have a several forms for you to complete.

Distribute in the following order: NASA-TLX, team workload, Job Satisfaction, and respective design form. Wait until they have finished each one, then collect form and distributed the next form.

We are about to begin Preliminary Design. Let me remind you that you have _________minutes to complete this project. Don't forget about your functional goals for preliminary design. You may begin preliminary design. Please record the start time in your log. Let me know when you have completed this phase.

Wait until they tell you they are finished with preliminary design.

Please record the stop time. You have now completed preliminary design. At this time I have a several forms for you to complete.

Distribute in the following order: NASA-TLX, team workload, Job Satisfaction, and respective design form. Wait until they have finished each one, then collect form and distributed the next form.

We are about to begin Detailed Design. Let me remind you that you have _________minutes to complete this project. Don't forget about your functional goals for detailed design. You may begin detailed design. Please record the start time in your log. Let me know when you have completed this phase.

Wait until they tell you they are finished with detailed design.

Please record the stop time. You have now completed detailed design. At this time I have a several forms for you to complete.

Distribute in the following order: NASA-TLX, team workload, Job Satisfaction, and respective design form. Wait until they have finished each one, then collect form and distributed the next form.

The team will build and test the final design three times for reliability and accuracy (same as during preliminary design) and three times for robustness. All results are recorded in the Log. The final lifecycle cost is calculated again after the testing is complete.

You have completed the formal design process. However, we need to see if your final prototype will meet the requirements. Following the instructions, [*the manufacturer needs to*] build the system. You will be timed. If you have a status meeting scheduled to occur during the manufacturing, please wait until you have finished with building the prototype to hold the status meeting. When you are building the prototype, only follow what is explicitly given to you in the drawings and instructions. [*The designer needs to*] Record design errors as they occur. If there are manufacturing are errors, point them out so they can be corrected and then make a note of it in the error report. You may begin building the system. Please record the start time in the log. As soon as the system is built, record the stop time.

Record the start time on the log. Wait until the prototype is ready:

Now we will test your system. Please record the start time. Set up your system and let me know when you are ready. We will run the test three times.

Complete the series of tests. Record results as they occur.

Now we will test for robustness. We will run the exact same set of tests as before, but now we will use a golf ball in place of the ping-pong ball. Please set up your system and let me know when you are ready.

Give participant(s) the golf ball. Record the results as they occur. Enter the stop time in the log after the last test is complete.

Thank you very much for participating in this experiment. I will let you know how your system ranked relative to the other systems once all of the trials are complete. Remember not to reveal any information about what you did today until after you have received the system rankings. If your system turns out to be the winner, I will be in contact with you to determine how to deliver your award. If your phone number or email changes before I contact you, please be sure to let me know.

Appendix A.4 Training Modules

A.4.1 Overview of Training Exercises

Three training exercises (from Meredith, 1997) related to the design project were used prior to the trial. Participants were trained for (1) detailed drawing, (2) LEGO™ assembly, and (3) lifecycle cost analysis. Participants assigned to manual or automated planning support were training in (1) developing scoping documents, (2) work breakdown structures, (3) Gantt charts, and (4) tracking. Those with automated support were also trained in Microsoft Project. The purpose of the exercises was to establish a baseline level of expertise. The script for the exercises is contained in the experimental instruction section (Appendix A.3). The written instructions are contained in Section A.4.3. The following sections provide an overview of each exercise and the instructional purpose of each exercise.

A.4.2 Learning Objectives

A.4.2.1 Detailed Drawing

The detailed drawing exercise consisted of developing a two-view drawing of a wheel and axle assembly. The exercise demonstrated:

- The method to orient the assembly in two-dimensional space.
- The method to dimension an assembly.
- The level of detailed required in the drawings

A.4.2.2 Assembly Exercise

The assembly exercise consisted of building a system from a set of parts and a three-view drawing of the system. The exercise demonstrated:

- How to read a three-view drawing.
- How to assemble LEGO™ pieces.
- How to use the LEGO™ motor in a system.

A.4.2.3 Life-cycle Cost Analysis Exercise

The life-cycle cost exercise demonstrated:

- The method to complete the life-cycle cost spreadsheet.
- The method to determine labor, material, spare and moving parts costs.

A.4.2.4 Planning and tracking a project

The project management training and associated exercises consisted of planning a project of the participants choice. Participants had to demonstrate:

- The method to develop a scoping document.
- The method to develop a work breakdown structure
- The method to create a Gantt chart
- How to create a budget
- How to calculate the cost performance index and schedule performance index

A.4.3 LEGOS Tutorial (adapted from Meredith, 1997)

As you probably already know, LEGOS are building blocks that come in a variety of sizes and shapes that you can use to build almost anything you can imagine. LEGOS sets also have mechanical parts, for example motors, gears, pulleys, and axles that allow you to build moving systems or systems with moving components.

You will be asked to design a prototype out of toys. The toys you will be using are LEGOS. The standard parts have dimensions that are multiples of 5/16th inch in length and width and 3/8th inch in height. The protrusions on each part are called studs, which enable parts to be attached together.

Standard parts come in two varieties: widths of one stud or two studs. We will call parts with one row of studs "singles" and parts with two rows of studs "doubles." Parts come in lengths ranging from one stud to 20 studs.

One of the standard parts is called a plate. Plates are either 1/8th or 3/8th inch thick. Plates can be used as the foundation for a system or as a surface that spans between parts, similar to a roof.

LEGOS parts come in a variety of colors; however color is not a consideration for this experiment.

Because it has probably been a while since you have used LEGOS lets look at some of these parts to make sure you understand how they work and can be assembled into a mechanical system.

You should have a reference document that contains a number of drawings of the various LEGO parts and how they can be assembled. You can use this reference document during the experiment.

Drawing 1 shows an axle and a beam. Axles are rods that come in a variety of lengths ranging from 1-1/4th inches to 3-3/4th inches. Axles can be used to mount gears, pulleys, and/or wheels. Beams are parts with a single row of studs that holes in them for axles to pass through. They range in size from 5/8th inch to 5 inches.

Drawing 2 shows an example of an axle and beam being used as a wheel assembly. Note that this assembly uses bushing to lock the axle in place.

Drawing 3 shows the bushing has two different types of ends. One end can be used to lock an axle and the other allows the axles to rotate.

Drawing 4 shows the use of gears. Gears come in a variety of sizes ranging from 8 teeth up to 40 teeth. We have normal gears, bevel gears that can be used with a differential to change the direction of a spinning axle, and two types of worm gears.

Drawing 5 shows the assembly of a differential. Differentials are used to change the plane of rotation like from the drive shaft of a car to an axle.

Drawing 6 shows a worm gear.

Drawing 7 shows how gears and pulleys can be connected to each other.

Drawing 8 shows how a motor can be connected to gears and pulley. Pulleys come in a 1-inch and 1 1/4th-inch size. Pulleys are also used as wheels. In other words, a pulley that fits tightly around the hub is a wheel. The motor that is available is a 4.5 volt motor that can produce 6000 revolutions per minute (RPMs) on its output axle. The motor is powered by three 1.5 volt batteries that are contained in a battery pack. The line connecting the motor to the battery pack is not very long so, if you use the motor, you may have to design the battery pack into your system.

There are also a number of miscellaneous pieces that you may need, for example connector pegs, bushings, pulleys, and rubber bands. Their use and function will be obvious in just a moment.

Now look at a series of pictures of systems that have been built using the parts. Drawing 9 shows the construction of a small car using a motor driving wheels using gears. Drawing 10 shows the construction of a small car using a motor driving wheels using a worm gear.

Drawing 11 shows a small car in which the battery pack has been designed into the car.

Drawing 12 shows that a bushing has two different ends. One end will allow the axle to rotate. The other end will lock the axle in place. (Participants have the original pictures and labels. If permission is granted by LEGOS the figures will be reproduced for this document).

In the table attached to this sheet, is a list of parts that are available to you and the quantity of parts available. What you see on the list is all we have, so make sure that your design does not call for any pieces that we don’t have or more of a particular piece than we have.

A.4.4 Detailed Drawing Tutorial (adapted from Meredith, 1997)

The purpose of this exercise is to demonstrate you know (1) how to draw a two-view drawing and (2) dimension a two-view drawing.

You must draw a two-view drawing (top and front views) of the wheel and axle connection on the desk in front of you. Note that the side view is redundant with the top view. Attempt this on your own and if you get stuck, ask the researcher for assistance.

When you are done, compare your drawing with the researcher's.

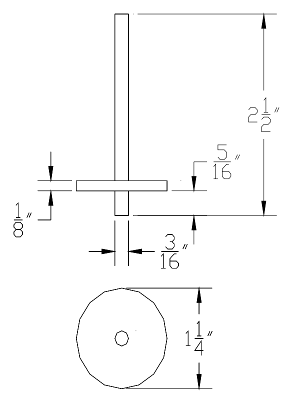


Figure 1 A two-view layout for an axle-tire connection

A.4.5 Assembly and Three-View Drawing Tutorial

The goal of this exercise is for you to demonstrate you know how to read a three-view drawing and can connect a LEGO motor to an axle.

Step 1: Verify that you have the following parts in your kit:

- 1 Motor
- 4 1 ¼” tires
- 2 5” beams
- 1 Standard brick (5/8 x 1 ¼)
- 2 1 ¼” beams
- 4 Technical plates (5/8 x 1 ¼)
- 2 2 ½” axles
- 1 Bevel gear (24 teeth)
- 1 Gear (8 teeth)
- 3 Bushings

Step 2: Using the three-view drawing in Figure 1, please assemble the car.

Step 3: When you are done, please notify the researcher to verify that you assembled the car correctly.

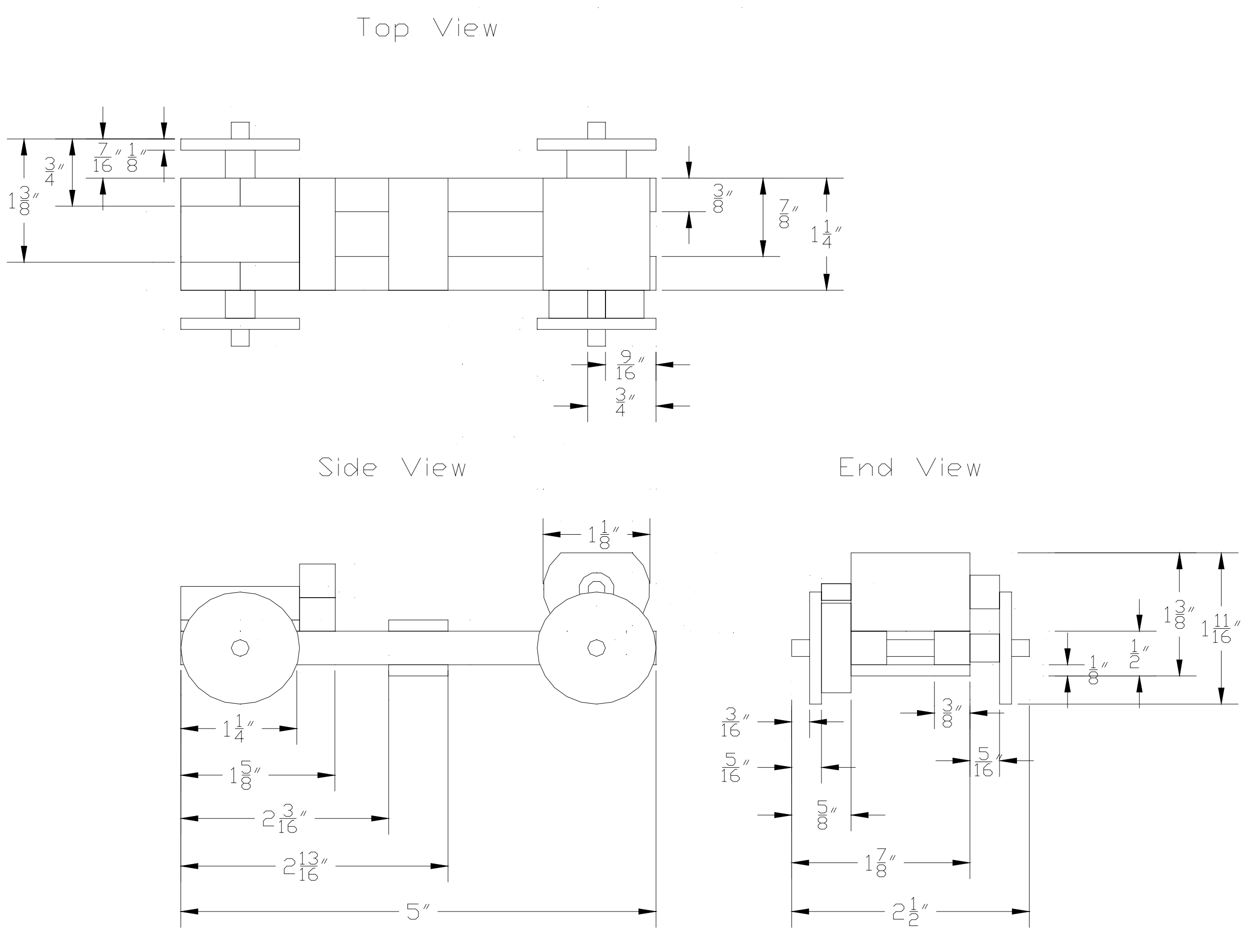


Figure 1 Three view drawing of the car

A.4.6 Lifecycle Cost Tutorial - Manual

The goal for this exercise is to show you how calculate the life-cycle cost. You will need to know how to calculate the life-cycle cost of your system.

Step 1: Write your team name, date, and number of members at the top of a blank sheet of paper. Table 1 below contains the parts list and labor times that have been used to build a system. Please determine the life-cycle costs for this system. The material costs are located in Table 2.

Table 1 Sample data for learning to calculate life-cycle costs

Number of team members	3
Conceptual Design Labor	25 minutes
Detail Design Labor	45 minutes
Manufacturing Labor	15 minutes
Testing Labor	10 minutes
Moving Parts	9
Materials	
5/8 x 1 ¼ inch standard brick	1
3/8 x 5/8 inch standard brick	1
Motor	1
Gears	2
Wheels (Tires)	4
Plates with holes	4
Axles	2
5 inch Beams	2
1 ¼ inch Beams	2
Bushings	3

Parts not listed on the life-cycle cost calculate template do not have an associated cost, but are counted as unique items, for example bushing.

Step 3: Determine the cost incurred during each phase. During design, the cost comes from labor. During Manufacturing the cost comes from labor and the materials used to build the system. The testing cost includes labor cost. Maintenance cost comes from the number of moveable parts (number of parts multiplied by $5.00) and the number of spare parts (10% of the total material cost). Once the individual costs have been determined, sum them to come up with a total life-cycle cost.

Step 4: Record the number of unique parts.

Step 5: When you have an answer ask the researcher for the key. Compare your answer with the correct answer, which is located on the key. If you did not get this answer, please recheck your input.

Step 6: When you have a correct answer, notify the researcher.

Table 2a Pricing List

Item Number	Cost Category	Units	Unit Price
Design Cost			
1	Conceptual Design Labor	Minutes	$1.00
2	Preliminary Design Labor	Minutes	$1.00
3	Detailed Design Labor	Minutes	$1.00
4	AutoCAD Cost	NA	$50.00
Manufacturing Cost			
5	Manufacturing Labor	Minutes	$1.00
6	Total Material Cost (From Bill of Material, Table 2b)	$	NA
Testing Cost			
7	Testing Labor	Minutes	$1.00
Maintenance			
8	Moving Parts	Each	$5.00
9	Spare Parts Cost (From Bill of Material, Table 2b)	NA	10% Total Material Cost
Total Life Cycle Cost			

Table 2b Bill of Materials

Item[1]	Dimension	Studs	Available	Used	Unit Cost	Cost
Bricks	5/8 x 2 ½	16	3		$16.00	
	5/8 x 2	12	4		$12.00	
	5/8 x 1 ¼	8	127		$8.00	
	5/8 x 1	6	34		$6.00	
	5/8 x 5/8	4	78		$4.00	
	3/8 x 2 ½	8	22		$8.00	
	3/8 x 2	6	34		$6.00	
	3/8 x 1 ¼	4	64		$4.00	
	3/8 x 1	3	32		$3.00	
	3/8 x 5/8	2	82		$2.00	
	3/8 x 3/8	1	86		$1.00	
Slopes	15/16 x 1 ¼	4	19		$4.00	
	15/16 x 5/8	2	4		$2.00	
Motor	4.5 Volt	NA	1		$100.00	
Gears	Various	NA	25		$25.00	
Pulleys/Wheels	Various	NA	7		$5.00	
Plates	3 1/8 x 6 ¼	200	2		$200.00	
	2 ½ x 5	128	1		$128.00	
	2 x 5	96	1		$96.00	
	2 x 3 1/8	60	2		$60.00	
	1 ¼ x 2 ½	32	2		$32.00	
Plate w/ Holes	Various	Various	15		$5.00	
Axles	Various	NA	10		$10.00	
Beams	5	16	2		$16.00	
	3 ¾	12	2		$12.00	
	2 ½	8	2		$8.00	
	2	6	2		$6.00	
	1 ¼	4	8		$4.00	
	5/8	2	12		$2.00	
Rubber Bands	Various	NA	1		$5.00	
Tape	½	NA	1		$5.00	
Cardboard	4 x 7	NA	1		$10.00	
Battery		NA	1		$100.00	
Miscellaneous	Various	NA	NA		$0.00	
			Total Parts		Total Material Cost	
			Moving Parts		Spare Parts Cost (10% of Total Cost)	
			Unique Parts			

[1]any part not listed is free, but must be included in the unique part count.

Key: Team Name:______________ Date:_________________ Number Team Members: _3_

Item Number	Cost Category	Units	Quantity	Unit Price	Amount
Design Cost					
1	Conceptual Design Labor	Minutes	25	$1.00	$75.00
2	Preliminary Design Labor	Minutes	60	$1.00	$180.00
3	Detailed Design Labor	Minutes	45	$1.00	$135.00
4	AutoCAD Cost	NA	NA	$50.00	$50.00
Manufacturing Cost					
5	Manufacturing Labor	Minutes	10	$1.00	$30.00
6	Total Material Cost (From Bill of Material)	$$	NA	NA	$260.00
Testing Cost					
7	Testing Labor	Minutes	10	$1.00	$30.00
Maintenance					
8	Moving Parts	Each	9	$5.00	$45.00
9	Spare Parts Cost (From Bill of Material)	NA	NA	NA	$26.00
Total Life Cycle Cost					$846

Bill of Materials

Item[1]	Dimension	Studs	Available	Used	Unit Cost	Cost
Bricks	5/8 x 2 ½	16	3		$16.00	
	5/8 x 2	12	4		$12.00	
	5/8 x 1 ¼	8	127	1	$8.00	$8.00
	5/8 x 1	6	34		$6.00	
	5/8 x 5/8	4	78		$4.00	
	3/8 x 2 ½	8	22		$8.00	
	3/8 x 2	6	34		$6.00	
	3/8 x 1 ¼	4	64		$4.00	
	3/8 x 1	3	32		$3.00	
	3/8 x 5/8	2	82	1	$2.00	$2.00
	3/8 x 3/8	1	86		$1.00	
Slopes	15/16 x 1 ¼	4	19		$4.00	
	15/16 x 5/8	2	4		$2.00	
Motor	4.5 Volt	NA	1	1	$100.00	$100.00
Gears	Various	NA	25	2	$25.00	$50.00
Pulleys/Wheels	Various	NA	7	4	$5.00	$20.00
Plates	3 1/8 x 6 ¼	200	2		$200.00	
	2 ½ x 5	128	1		$128.00	
	2 x 5	96	1		$96.00	
	2 x 3 1/8	60	2		$60.00	
	1 ¼ x 2 ½	32	2		$32.00	
Plate w/ Holes	Various	Various	15	4	$5.00	$20.00
Axles	Various	NA	10	2	$10.00	$20.00
Beams	5	16	2	2	$16.00	$32.00
	3 ¾	12	2		$12.00	
	2 ½	8	2		$8.00	
	2	6	2		$6.00	
	1 ¼	4	8	2	$4.00	$8.00
	5/8	2	12		$2.00	
Rubber Bands	Various	NA	1		$5.00	
Tape	½	NA	1		$5.00	
Cardboard	4 x 7	NA	1		$10.00	
Battery		NA	1		$100.00	
Miscellaneous	Various	NA	NA	3	$0.00	$0.00
			Total Parts	19	Total Material Cost	$260.00
			Moving Parts	9	Spare Parts Cost (10% of Total Cost)	$26.00
			Unique Parts	10		

1any part not listed is free, but must be included in the unique part count.

Appendix A.5 Informed Consent Forms

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants
in Research Projects Involving Human Subjects

Title of Project: An Analysis of Team Design and Project Management Support during a Design Project's Lifecycle
Investigator(s): Paige E. Smith

I. Purpose of this Research/Project

You are invited to participate in a study investigating engineering design projects. This study will explore the effects of project management support and various engineering team designs to determine if one combination is best. Approximately 72 participants will be needed for this research.

II. Procedures

You will be assigned to one of two team designs: individual design or group design. You will apply the principles of engineering design to develop a system during which your performance will be determined. The experiment is designed to take between three and four hours. As part of the data collection procedure you will complete several forms including a mental workload scale and job satisfaction questionnaire. Participants in the group design will have an additional workload scale to complete.

Depending on the treatment you are assigned to, you will need to participate in either a one-hour training session or a four-hour training session.

III. Risks

There are no more than minimal risks associated with this research.

IV. Benefits

This research will add to the body of knowledge on the proper support for engineering design projects. In addition, the effects of collaborating will be studied. No promise or guarantee of benefits has been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

The results of this study will be kept strictly confidential. Individuals participating will not be identified except to the research team.

Some of the trials will be video/audio taped. The investigator will maintain these tapes and no one outside of the research team will have access to the tapes. The tapes will be locked in 1106 Glenn L. Martin Hall. These tapes will be destroyed upon completion of the dissertation.

VI. Compensation

No monetary compensation will be provided for participation in this experiment. However, a cash award bonus of $100 will be given to each member of the group or the individual that achieves the highest level of performance in the experiment.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

______________________________ ______________________________
IRB Approval Date Approval Expiration Date

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I agree to abide by all of the rules of the experiment. I also agree not to discuss any aspect of this research with others, except my teammates, upon the conclusion of my participation in the study.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date ______________________________
Subject signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Paige E. Smith (301) 405-3931/pesmith@deans.umd.edu
Student Investigator Telephone/e-mail

Dr. Brian M. Kleiner (540) 231-4926/bkleiner@vt.edu
Faculty Advisor Telephone/e-mail

Dr. Linda C. Schmidt (301) 405-0417/lschmidt@eng.umd.edu
Faculty Advisor Telephone/e-mail

Dr. Robert J. Beaton (540) 231-8748/bobb@vt.edu
Departmental Reviewer Telephone/e-mail

David M. Moore (540) 231-4991/moored@vt.edu
Chair, IRB Telephone/e-mail
Office of Research Compliance
Research & Graduate Studies

This Informed Consent is valid from ________ to ________.

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: An Analysis of Team Design and Project Management Support during a Design Project's Lifecycle

Statement of Age of Subject

I state that I am over 18 years of age, in good physical health, and wish to participate in a program of research begin conducted by Dr. Linda C. Schmidt in the Department of Mechanical Engineering at the University of Maryland, College Park, MD 20742.

Purpose of this Research/Project

You are invited to participate in a study investigating engineering design projects. This study will explore the effects of project management support and various engineering team designs to determine if one combination is best. Approximately 72 participants will be needed for this research.

Procedures

You will be assigned to one of two team designs: individual design or group design. You will apply the principles of engineering design to develop a system during which your performance will be determined. The experiment is designed to take between three and four hours. As part of the data collection procedure you will complete several forms including a mental workload scale and job satisfaction questionnaire. Participants in the group design will have an additional workload scale to complete. Depending on the treatment you are assigned to, you will need to participate in either a one-hour training session or a four-hour training session.

Extent of Anonymity and Confidentiality

The results of this study will be kept strictly confidential. Individuals participating will not be identified except to the research team.

Some of the trials will be video/audio taped. The investigator will maintain these tapes and no one outside of the research team will have access to the tapes. The tapes will be locked in 1106 Glenn L. Martin Hall. These tapes will be destroyed upon completion of the dissertation.

Risks

There are no risks associated with this research.

Benefits, Freedom to Withdraw, and Ability to ask questions

This research will add to the body of knowledge on the proper support for engineering design projects. In addition, the effects of collaborating will be studied. No promise or guarantee of benefits has been made to encourage you to participate.

You are free to ask questions or withdraw from this study at any time without penalty.

Compensation

No monetary compensation will be provided for participation in this experiment. However, a cash award bonus of $100 will be given to each member of the group or the individual that achieves the highest level of performance in the experiment.

Subject's Responsibilities

I voluntarily agree to participate in this study. I agree to abide by all of the rules of the experiment. I also agree not to discuss any aspect of this research with others, except my teammates, upon the conclusion of my participation in the study.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date ______________
Subject Signature

____ Date ______________
Subject Printed Name

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Dr. Linda C. Schmidt Faculty Advisor	(301) 405-0417/lschmidt@eng.umd.edu Telephone/e-mail 3163 Martin Hall, College Park, MD 20742-3035 Address
Dr. Brian M. Kleiner Faculty Advisor	(540) 231-4926/bkleiner@vt.edu Telephone/e-mail
Paige E. Smith Student Investigator	(301) 405-3931/pesmith@deans.umd.edu Telephone/e-mail

Appendix A.6 Laboratory Setup Checklist

Forms:
- Consent Form
- Demographic Form
- NASA-TLX (4/participant in unsupported, 5/participant in supported)
- Job Satisfaction (4/participant in unsupported, 5/participant in supported; includes the supplemental questions)
- Group workload scales (groups only: 4/participant in unsupported, 5/participant in supported)
- Planning Form (Supported only: Scoping document, WBS, Gantt chart, and tracking form)
- Conceptual Design Form
- Preliminary Design Form
- Detailed Design Form
- Post-experiment Form
- Researcher's Log
- Time Log

Outputs:
- Planning Form
  - Scoping document (pencil/paper or Microsoft Word document)
  - WBS (pencil/paper or Microsoft Project Document)
  - Gantt chart (pencil/paper or Microsoft Project Document)
  - Budget (pencil/paper or Microsoft Project Document)
  - Tracking (pencil/paper or Microsoft Project & pencil/paper)
- Conceptual Design Form
  - Team Goal
  - System Requirements
  - Idea List
- Preliminary Design Form
  - Description and Sketch of two high level concepts
  - Trade off analysis (Strengths and weaknesses, cost estimate)
  - Concept Decision
- Detailed Design Form
  - Justification for concept selection
  - Detailed drawing of two views and the point of contact with the payload
  - Manufacturing instructions
  - Bill of Material
  - Rough Lifecycle cost calculation
- Post testing
  - Life-cycle cost calculation

Miscellaneous:
- Videotape

Appendix A.7 Data Collection Logs and Forms

Training – Training **Condition:_______**

Date:______________________

Project Management Training Start Time:_____________

Finish Time:________________

Person 1

Detailed Drawing Start Time:_________________Finish Time:___________

Assembly Start Time:_________________Finish Time:___________

Lifecycle cost Start Time:_________________Finish Time:___________

Total Time Elapsed:___________

Person 2

Detailed Drawing Start Time:_________________Finish Time:___________

Assembly Start Time:_________________Finish Time:___________

Lifecycle cost Start Time:_________________Finish Time:___________

Total Time Elapsed:___________

Person 3

Detailed Drawing Start Time:_________________Finish Time:___________

Assembly Start Time:_________________Finish Time:___________

Lifecycle cost Start Time:_________________Finish Time:___________

Total Time Elapsed:___________

Person 4

Detailed Drawing Start Time:_________________Finish Time:___________

Assembly Start Time:_________________Finish Time:___________

Lifecycle cost Start Time:_________________Finish Time:___________

Total Time Elapsed:___________

Trial Log

Conceptual Design

Start Time:__________________

Finish Time:_________________

Total Time Elapsed:___________

1. How many of the system requirements were appropriately identified?__________
2. How many ideas were generated?___________________

Preliminary Design

Start Time:__________________

Finish Time:_________________

Total Time Elapsed:___________

Functional effectiveness:
Design: Process Time:____________

Manufacturing: Cube Size:_______________(complete later)

Finance: Moving Parts:____________(complete later)

Detailed Design

Start Time:__________________

Finish Time:_________________

Total Time Elapsed:___________

Functional effectiveness:
Design: Process Time:_______

Manufacturing Unique Parts:_______(complete later)

Finance Life-Cycle Cost:_____(complete later)

Testing:

Start Time:__________________

Finish Time:_________________

Total Time Elapsed:___________

1. Range and Accuracy
500 Ball crossed finish line
400 Ball crossed extended line
200 Ball crossed hurdle line
0 Ball didn't cross hurdle

Reliability	Robustness
Test 1_________	Test 1_________
Test 2_________	Test 2_________
Test 3_________	Test 3_________
Average________	Average________

2. Size

500 Size ≤ 50 in^3
400 50 in^3 < Size ≤ 100 in^3
300 100 in^3 < Size ≤ 150 in^3
200 150 in^3 < Size ≤ 200 in^3
100 Size > 200 in^3

Size:__________________

3. Manufacture

500 build time ≤ 5 min
400 5 min < build time ≤ 10 min^3
300 10 min < build time ≤ 15 min
200 15 min < build time ≤ 20 min
100 build time > 20 min

Manufacture:__________________

3. System Effectiveness= $\frac{avg.reliability + avg.robust}{2} + size + manufacture$:________________

4. Life-Cycle Cost:_____________________

5. Cost Effectiveness = $\frac{systemeffectiveness}{lifecycle\cos t}$:_____________

6. Design Cycle Time:____________

7. Design Cost:_____________

8. Material Cost:____________

Total Experiment Time______________

Abnormalities Observed:

Other Observations:

Status Reports (every 30 minutes):

Period 1

Start time: ____________________

Stop time: ____________________

CPI:_________

SVI:_________

Period 2

Start time: ____________________

Stop time: ____________________

CPI:_________

SVI:_________

Period 3

Start time: ____________________

Stop time: ____________________

CPI:_________

SVI:_________

Time Log for conditions with planning

	Start Time	Finish Time	Time Elapsed
Planning			

	Start Time	Finish Time	Time Elapsed
Conceptual Design			
Preliminary Design			
Detailed Design			
Manufacturing (building)			
Testing			
		Total Time Elapsed	

	Start Time	Finish Time	Time Elapsed
Status Meeting 1			
Status Meeting 2			
Status Meeting 3			
		Total Time Elapsed	

Time Log for conditions without planning

	Start Time	Finish Time	Time Elapsed
Conceptual Design			
Preliminary Design			
Detailed Design			
Manufacturing (building)			
Testing			
		Total Time Elapsed	

Conceptual Design Form

Goal:

____

____

____

Design Criteria:

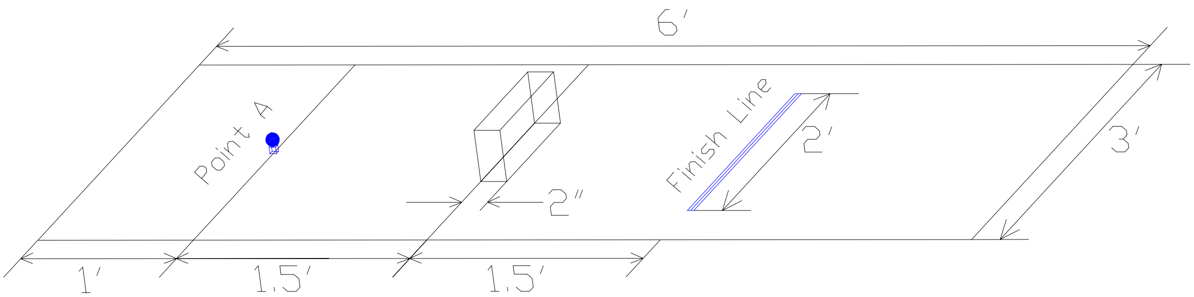
List of Concepts:

Preliminary Design Concept Form – System A

Date:____________________________

Please describe the design approach for System A that has been selected as one of two potential concepts to achieve this task. You do not need to be specific at this time.

System Concept Diagram – System A

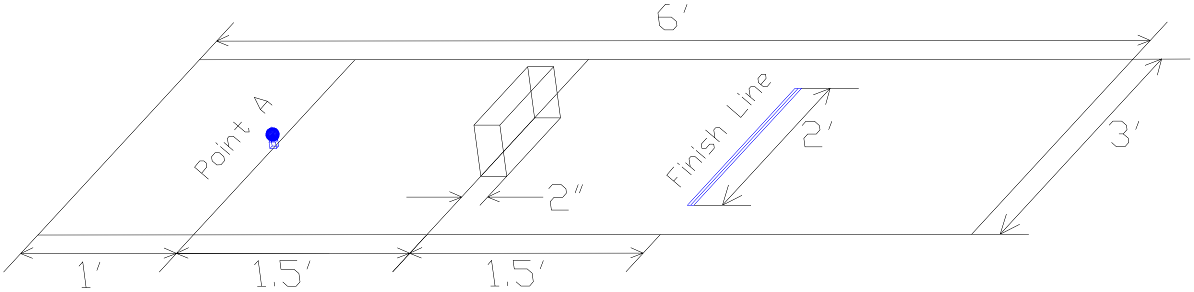


Preliminary Design Concept Form – System B

Date:___________________________

Please describe the design approach for System B that has been selected as one of two potential concepts to achieve this task. You do not need to be specific at this time.

System Concept Diagram – System B



Tradeoff Analysis:

System A	System B
Strengths	Strengths
Weaknesses	Weaknesses
Lifecycle Cost Estimate:_____________________	Lifecycle Cost Estimate:_____________________

Lifecycle Cost Calculation form

Date:__________________ Number Team Members:_____

Item Number	Cost Category	Units	Quantity	Unit Price	Amount
Design Cost					
1	Conceptual Design Labor	Minutes		$1.00	
2	Preliminary Design Labor	Minutes		$1.00	
3	Detailed Design Labor	Minutes		$1.00	
Manufacturing Cost					
4	Manufacturing Labor	Minutes		$1.00	
5	Total Material Cost	$	NA	NA	
Testing Cost					
6	Testing Labor	Minutes		$1.00	
Maintenance					
7	Moving Parts	Each		$5.00	
8	Spare Parts Cost	NA	NA	(10% total material cost)	
Total Life Cycle Cost					

Bill of Materials

Item[1]	Dimension	Studs	Available	Used	Unit Cost	Cost
Bricks	5/8 x 2 1/2	16	3		$16.00	
	5/8 x 2	12	4		$12.00	
	5/8 x 1 1/4	8	127		$8.00	
	5/8 x 1	6	34		$6.00	
	5/8 x 5/8	4	78		$4.00	
	3/8 x 2 1/2	8	22		$8.00	
	3/8 x 2	6	34		$6.00	
	3/8 x 1 1/4	4	64		$4.00	
	3/8 x 1	3	32		$3.00	
	3/8 x 5/8	2	82		$2.00	
	3/8 x 3/8	1	86		$1.00	
Slopes	15/16 x 1 1/4	4	19		$4.00	
	15/16 x 5/8	2	4		$2.00	
Motor	4.5 Volt	NA	1		$100.00	
Gears	Various	NA	25		$25.00	
Pulleys/Wheels/Tires	Various	NA	7		$5.00	
Plates	3 1/8 x 6 1/4	200	2		$200.00	
	2 1/2 x 5	128	1		$128.00	
	2 x 5	96	1		$96.00	
	2 x 3 1/8	60	2		$60.00	
	1 1/4 x 2 1/2	32	2		$32.00	
Plates with holes	Various	< 17	14		$5.00	
Axles	Various	NA	10		$10.00	
Beams	5	16	2		$16.00	
	3 3/4	12	2		$12.00	
	2 1/2	8	2		$8.00	
	2	6	2		$6.00	
	1 1/4	4	8		$4.00	
	5/8	2	12		$2.00	
Rubber Bands	Various	NA	19		$5.00	
Tape	1”	NA	1		$5.00	
Cardboard	4 x 7	NA	1		$10.00	
Miscellaneous	Various	NA	NA		$0.00	
			Total Parts		Total Material Cost	
			Moving Parts		Spare Parts Cost (10% of Total Cost)	
			Unique Parts			

[1]any part not listed is free, but must be included in the unique part count.

Budget:

		Cost by Period (30 minutes)					
		1		2		3	
	Total Budgeted	P	A	P	A	P	A
Conceptual Design							
Preliminary Design							
Detailed Design							
Manufacturing & Testing							
Period Total							
Cumulative							
		BCWS	ACWS	BCWS	ACWS	BCWS	ACWS

Cumulative Percent Completed

	Period		
	1	2	3
Conceptual Design			
Preliminary Design			
Detailed Design			
Manufacturing & Testing			

Cumulative budgeted cost for the work performed

		Period		
	Total Budgeted Cost	1	2	3
Conceptual Design				
Preliminary Design				
Detailed Design				
Manufacturing and Testing				
Cumulative				
		BCWP	BCWP	BCWP

Period 1:

BCWS___________________ACWS___________________BCWP__________________

CPI=BCWP/ACWS=______________________________________

SPI=BCWP/BCWS=_______________________________________

Period 2:

BCWS___________________ACWS___________________BCWP__________________

CPI=BCWP/ACWS=______________________________________

SPI=BCWP/BCWS=_______________________________________

Period 3:

BCWS___________________ACWS___________________BCWP__________________

CPI=BCWP/ACWS=______________________________________

SPI=BCWP/BCWS=_______________________________________

Appendix A.8 Engineering Design Goals

Conceptual Design

Design Goals: As a designer, you need to be able to elicit all of the systems requirements from the customer, and the manufacturing and finance representatives. This will save you a great deal of hassle later in the design. You should try to come up with as many potential ideas as possible.

Manufacturing Goals: As a manufacturing representative, you recognize that the capabilities of your manufacturing facility are limited. Therefore, you want to keep the system as simple as possible.

Purchasing Goals: As the representative from finance, you want to keep the life-cycle cost as low as possible. You recognize that the more time you spend in conceptual design the more expensive your overall system will be, therefore you want to minimize the time spent in conceptual design.

Preliminary Design

Design Goals: As a designer, during preliminary design, you want to attempt to have a design that is robust as possible. Robust means the design will work with minor changes in specifications. To get to this point, you want consider at least two designs in greater detail before selecting a single design to be developed in greater detail.

Manufacturing Goals: As a manufacturing representative, you recognize that the size of your facility is rather small. Therefore, you want to try to keep the size of the system as small as possible. Size will be measured as the smallest volumetric box that will encase the system.

Purchasing Goals: As the representative from finance, you want to keep the life-cycle cost as low as possible. You recognize that the more moving parts there are in the system the more expensive it will be to manufacture. Therefore you want to keep the system as simple as possible by minimizing the number of moving parts. In addition, you realize that time is money…therefore you also want to keep the pace of the preliminary design moving.

Detailed Design

Design Goals: Designers are frequently measured on their ability to release drawings in a timely manner. Your goal is to try to complete the detailed design and issue manufacturing instructions as quickly as possible but with as few errors as possible.

Manufacturing Goals: The manufacturer prefers to fabricate as many standard parts as possible as opposed to unique parts. Your goal is to influence the design to use as few unique parts as possible.

Purchasing Goals: As the representative from finance, you are responsible for the life-cycle cost. Your goal is to influence the design such that the life-cycle cost is as low as possible. You will also be responsible for the calculation of life-cycle cost.

In the conditions where an individual work alone, he or she was given all of the goals.

Appendix A.9 AICC Results

All mixed designs were subject to a goodness of fit test to determine which variance grouping should be used. When the standard ANOVA procedures could not be used due to a violation in the underlying assumptions for the ANOVA calculations, the data were checked to determine if a variance grouping by factor would correct the violation or if a transformation was needed. The tables in this appendix provide a summary of the results for the variables from mixed designs and those that violated the ANOVA assumptions. The first column contains the factor name. Column two systematically lists each variance grouping for the model (U=ungrouped or standard ANOVA, TD=team design, PS=project support, DP=design phase). The third column contains the AICC which is a goodness of fit statistic in which lower numbers indicates a better fit. The last column contains the normality verification. Recall from the explanation in Chapter 4, that the AICC was calculated for the ungrouped data first. Each factor is subsequently checked and if the AICC for the factor grouping is smaller than the AICC of the ungrouped data by at least 2.0, the smaller AICC grouping is selected indicating a better fit of the data (denoted by the bold face type). The last step is to determine if the data are normal within the factor-level groupings. If the data were normal then the grouping is selected. If not, a data transformation was attempted (reported in Chapter 4).

Table A. 9.1 Comparison of the goodness of fit for mixed subject designs and when ANOVA assumptions are violated for data from Chapter 4 to determine the variance grouping (U=ungrouped, PS=project support, TD=team design, DP=design phase)

Variable	Variance Grouping	AICC	Normality (V=violated, S=satisfied, blank=not tested)
Reflective			
Cost Effectiveness	U	114.6	V
	TD	105.9	V
	PS	105.2	V
NASA TLX	U	127.8	
	TD	**124.2**	**S**
	PS	126.0	
Job Satisfaction	U	228.9	
	TD	**225.3**	**S**
	PS	229.6	
Design Process			
Time in Phase	U	709.6	
	TD	711.3	
	PS	710.6	
	DP	**678.7**	**S**
NASA TLX	U	392.2	
	TD	**383.4**	**S**
	PS	396.3	
	DP	396.1	
Job Satisfaction	U	617.3	
	TD	**606.7**	**S**
	PS	613.1	
	DP	609.9	
Time in Status Report	**U**	**238.4**	**S**
	TD	241.8	
	PS	243.6	
	Time	247.1	

Table A.9.1 Comparison of goodness of fit for Chapter 4 data to determine variance grouping (continued)

Variable	Variance Grouping	AICC	Normality
Design Process			
Cost Performance Index	U	4.0	
	TD	5.8	
	PS	5.8	
	Time	**-2.0**	**S**
Schedule Performance Index	U	-0.1	
	TD	0.2	
	PS	1.9	
	Time	**-3.3**	**S**

Table A. 9.2 Comparison of the AICC for each factor from Chapter 5 to determine the grouping when normality or homogeneity of variance assumption is violated

Variable	Variance Grouping	AICC	Normality (V=violated, S=satisfied, blank=not tested)
Planning			
NASA TLX			
Physical Demand	U	99.4	V
	TD	93.6	V
	PS	93.5	V
Job Satisfaction			
Comfort			
Personal Problems	U	77.8	
	TD	**75.4**	**S**
	PS	75.9	
Resources	U	91.7	S
	TD	**88.1**	**S**
	PS	88.4	
Responsibility	U	**65.8**	**S**
	TD	67.7	
	PS	66.9	
Design Process			
NASA TLX			
Mental	U	486.1	
	TD	**479.7**	**S**
	PS	483.8	
	DP	486.8	
Physical	**U**	**532.6**	**S**
	TD	532.5	
	PS	536.9	
	DP	534.3	
Temporal	**U**	**511.7**	**S**
	TD	512.8	
	PS	514.8	
	DP	513.2	
Performance	U	505.5	
	TD	**490.9**	**S**
	PS	496.0	
	DP	496.7	

Table A.9.2 Comparison of the AICC for each factor from Chapter 5 (continued)

Variable	**Variance Grouping**	**AICC**	**Normality**
Design Process			
Effort	U	481.6	
	TD	**479.0**	**S**
	PS	482.4	
	DP	484.0	
Frustration	**U**	**560.5**	**S**
	TD	561.7	
	PS	564.0	
	DP	560.8	
Job Satisfaction			
Comfort	U	446.1	
	TD	**441.0**	**S**
	PS	450.1	
	DP	Infinite likelihood	
Perceived time	U	329.8	
	TD	**327.2**	**S**
	PS	332.9	
	DP	329.2	
Excessive work	U	262.0	
	TD	241.9	V
	PS	261.1	
	DP	**243.3**	**S**
Physical surrounding	**U**	**193.0**	**S**
	TD	Infinite likelihood	
	PS	197.2	
	DP	194.4	
Personal problems	U	234.7	
	TD	234.7	
	PS	**224.3**	**S**
	DP	230.6	
Challenge	U	474.3	
	TD	272.7	
	PS	475.7	
	DP	**468.6**	**S**
Ability	U	241.7	
	TD	**228.8**	**S**
	PS	241.2	
	DP	235.6	
Interesting	U	260.2	
	TD	**253.2**	**S**
	PS	261.8	
	DP	257.3	
Freedom	U	285.4	
	TD	278.1	
	PS	284.5	
	DP	**264.6**	**S**
Difficult Problem	U	244.5	
	TD	239.8	
	PS	239.0	
	DP	**226.2**	**S**

Table A.9.2 Comparison of the AICC for each factor from Chapter 5 (continued)

Variable	**Variance Grouping**	**AICC**	**Normality**
Design Process			
Results	**U**	**272.0**	**S**
	TD	270.6	
	PS	273.0	
	DP	270.2	
Resources	U	430.4	
	TD	**412.3**	**S**
	PS	422.5	
	DP	425.0	
Equipment	U	262.1	
	TD	260.3	
	PS	259.3	
	DP	**258.8**	**S**
Information	U	320.5	
	TD	**299.8**	**S**
	PS	318.7	
	DP	318.6	
Responsibility	U	245.4	
	TD	**231.2**	**S**
	PS	237.3	
	DP	243.0	
Supplemental Questions			
Doubt	U	302.0	
	TD	**295.8**	**S**
	PS	299.6	
	DP	303.5	
Ease of Use	**U**	**177.1**	**S**
	TD	176.4	
	PS	176.7	
	DP	178.1	
Efficiency	**U**	**192.3**	**S**
	TD	192.5	
	PS	191.5	
	DP	191.6	
Effectiveness	**U**	**193.4**	**S**
	TD	193.8	
	PS	195.5	
	DP	196.9	
Productivity	U	223.2	
	TD	**220.6**	**S**
	PS	222.7	
	DP	226.1	
Satisfaction	U	193.7	
	TD	195.0	
	PS	195.9	
	DP	**188.3**	**S**

Table A.9.2 Comparison of the AICC for each factor from Chapter 5 (continued)

Variable	Variance Grouping	AICC	Normality
Reflective			
Design Cost	U	305.6.6	
	TD	**294.7**	**S**
	PS	310.5	
NASA TLX			
Mental	U	167.6	V
	TD	169.1	
	PS	**167.2**	**S**
Effort	U	163.6	
	TD	**161.6**	**S**
	PS	166.0	
Job Satisfaction			
Comfort			
Personal Problems	U	113.9	
	TD	**105.3**	**S**
	PS	115.0	
Challenge			
Interesting	U	84.2	
	TD	79.7	
	PS	**72.1**	**S**
Freedom	U	107.1	
	TD	**99.9**	**S**
	PS	108.3	
Problem	U	71.4	
	TD	**68.6**	**S**
	PS	74.5	
Resource			
Information	U	98.0	
	TD	**94.7**	**S**
	PS	96.2	
Responsibility	U	95.3	
	TD	**85.8**	**S**
	PS	89.2	
Supplement Questions			
Equipment	U	105.3	
	TD	**94.8**	**S**
	PS	109.9	
Excess work	U	108.9	
	TD	**103.7**	**S**
	PS	105.4	

Table A. 9.3 Comparison of the AICC for each factor in the analysis of group members (Chapter 6)

Variable	Variance Grouping	AICC	Normality (V=violated, S=satisfied, blank=not tested)
Planning			
NASA TLX			
Physical	U	142.9	
	PS	142.4	
	R	140.1	V
Job Satisfaction			
Challenge	U	185.3	
	PS	187.2	
	R	**178.6**	**S**
Ability	U	112.7	
	PS	**106.0**	**S**
	R	114.3	
Resources			
Competent	U	97.9	
	PS	**92.9**	**S**
	R	100.0	
Supplemental Questions			
Efficient	U	118.8	
	PS	118.3	
	R	115.2	V
Perceived Time	U	121.1	
	PS	114.1	V
	R	125.6	
Critical Team behaviors			
Total ineffective	U	103.2	V
	PS	96.3	V
	R	102.9	
Ineffective accept feedback	U	-9.5	V
	PS	Did not converge	
	R	Did not converge	
Effective accept feedback	U	32.5	V
	PS	12.9	V
	R	35.4	
Effective adaptability	U	51.0	V
	PS	49.8	
	R	54.9	

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	Variance Grouping	AICC	Normality
Planning			
Ineffective communication	U	61.1	V
	PS	27.7	V
	R	58.9	
Effective communication	U	40.3	V
	PS	35.3	
	R	32.6	V
Ineffective cooperation	U	59.8	V
	PS	60.8	
	R	63.6	
Ineffective coordination	U	39.1	V
	PS	35.1	V
	R	Infinite likelihood	
Effective coordination	U	145.5	V
	PS	141.5	
	R	147.4	V
Ineffective give feedback	U	12.1	V
	PS	Did not converge	
	R	Infinite likelihood	
Ineffective team spirit	U	11.3	V
	PS	13.6	
	R	Did not converge	
Design Process			
NASA TLX	**U**	**617.6**	**S**
	PS	619.6	
	R	620.8	
	DP	618.7	
Mental	U	791.9	
	PS	792.7	
	R	795.5	
	DP	**786.8**	**S**
Physical	U	853.2	
	PS	857.1	
	R	857.4	
	DP	**834.1**	**S**
Temporal	U	840.8	
	PS	**835.0**	**S**
	R	845.0	
	DP	844.6	
Performance	U	756.8	
	PS	**750.5**	**S**
	R	755.1	
	DP	760.7	
Effort	**U**	**781.5**	**S**
	PS	785.1	
	R	782.1	
	DP	781.9	
Frustration	**U**	**886.5**	**S**
	PS	888.1	
	R	890.1	
	DP	886.8	

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	**Variance Grouping**	**AICC**	**Normality**
Design Process			
Job Satisfaction	**U**	**974.5**	**S**
	PS	974.7	
	R	975.2	
	DP	975.2	
Comfort	**U**	**725.4**	**S**
	PS	723.7	
	R	726.4	
	DP	724.6	
Excess work	U	450.3	
	PS	454.0	
	R	453.2	
	DP	**438.4**	**S**
Physical surroundings	U	374.4	
	PS	360.9	
	R	**360.5**	**S**
	DP	376.9	
Perceived time	U	543.1	
	PS	545.8	
	R	544.3	
	DP	**529.9**	**S**
Personal problems	U	426.3	
	PS	412.7	
	R	**397.1**	**S**
	DP	425.9	
Challenge	U	780.7	
	PS	780.0	
	R	783.9	
	DP	**778.1**	**S**
Ability	U	429.7	
	PS	431.5	
	R	**426.3**	**S**
	DP	433.8	
Interest	U	426.8	
	PS	427.2	
	R	422.0	
	DP	**406.2**	**S**
Freedom	U	483.0	
	PS	485.7	
	R	483.6	
	DP	**479.6**	**S**
Problem	U	451.1	
	PS	**442.1**	**S**
	R	453.9	
	DP	453.1	
Results	**U**	**477.9**	**S**
	PS	481.2	
	R	479.3	
	DP	480.7	

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	Variance Grouping	AICC	Normality
Design Process			
Resources	**U**	**714.3**	**S**
	PS	718.0	
	R	716.1	
	DP	715.0	
Equipment	**U**	**449.4**	**S**
	PS	447.7	
	R	449.8	
	DP	450.3	
Information	U	440.5	
	PS	440.1	
	R	**422.6**	**S**
	DP	434.4	
Responsibility	**U**	**382.5**	**S**
	PS	386.2	
	R	381.4	
	DP	383.8	
Competence	U	404.4	
	PS	404.0	
	R	404.1	
	DP	**395.7**	**S**
Helpful	U	459.2	
	PS	459.7	
	R	458.7	
	DP	435.4	V
Supplemental Design Questions			
Doubt	**U**	**498.3**	**S**
	PS	499.0	
	R	501.0	
	DP	500.9	
Supplemental Planning Questions			
Ease of Use	**U**	**294.9**	**S**
	PS	293.6	
	R	297.6	
	DP	296.9	
Efficiency	**U**	**319.1**	**S**
	PS	320.8	
	R	323.4	
	DP	320.2	
Effectiveness	**U**	**318.5**	**S**
	PS	319.1	
	R	322.4	
	DP	317.0	
Productivity	**U**	**358.2**	**S**
	PS	359.8	
	R	361.7	
	DP	358.0	
Satisfaction	**U**	**312.7**	**S**
	PS	359.8	
	R	361.7	
	DP	358.0	

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	**Variance Grouping**	**AICC**	**Normality**
Design Process			
Group Workload			
Value of group interaction	U	840.3	
	PS	843.4	
	R	843.5	
	DP	**823.2**	**S**
Difficulty of group interaction	**U**	**884.9**	**S**
	PS	886.9	
	R	886.5	
	DP	884.0	
Degree of cooperation	U	817.7	
	PS	820.5	
	R	821.5	
	DP	**805.0**	**S**
Overall team workload	**U**	**812.1**	**S**
	PS	814.1	
	R	815.8	
	DP	814.5	
Critical Team Behaviors			
Total effective	U	753.1	
	PS	750.8	
	R	751.1	
	DP	**724.4**	**S**
Total ineffective	U	450.7	
	PS	454.9	
	R	445.4	
	DP	**417.5**	**S**
Ineffective accept feedback	U	-143.8	V
	PS	-163.2	V
	R	Did not converge	
	DP	Infinite likelihood	
Effective accept feedback	U	108.6	V
	PS	94.9	V
	R	106.7	
	DP	Did not converge	
Ineffective adapt	U	-74.9	V
	PS	Infinite Likelihood	
	R	-116.7	V
	DP	Infinite Likelihood	
Effective adapt	U	247.9	
	PS	242.5	
	R	239.5	S
	DP	Infinite likelihood	
Ineffective communication	U	245.5	
	PS	245.5	
	R	249.0	
	DP	**239.9**	**S**
Effective communication	U	93.8	V
	PS	85.3	V
	R	96.1	
	DP	97.9	

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	Variance Grouping	AICC	Normality
Design Process			
Ineffective cooperation	U	167.8	V
	PS	157.8	V
	R	145.7	V
	DP	Infinite likelihood	
Effective cooperation	U	559.6	
	PS	546.7	
	R	553.8	
	DP	**544.7**	**S**
Ineffective coordination	U	279.6	V
	PS	278.5	
	R	249.2	
	DP	239.6	V
Effective coordination	U	565.8	
	PS	569.8	
	R	567.8	
	DP	**553.6**	**S**
Ineffective give feedback	U	-28.2	V
	PS	-25.2	
	R	Infinite likelihood	
	DP	Did not converge	
Effective give feedback	U	431.8	S
	PS	435.5	
	R	435.6	
	DP	**422.9**	**S**
Ineffective team spirit	U	147.0	V
	PS	150.5	
	R	151.1	
	DP	Infinite likelihood	
Effective team spirit	U	225.1	V
	PS	229.2	
	R	229.0	
	DP	221.0	V
Supplemental Group Observations			
Time	U	456.4	
	PS	457.9	
	R	**449.9**	**S**
	DP	**449.9**	**S**
Money	U	639.4	
	PS	634.6	
	R	618.2	
	DP	**602.8**	**S**
Non-task	U	287.2	
	PS	290.3	
	R	285.1	
	DP	**267.6**	**S**

Table A.9.3 Comparison of the AICC for each factor for the analysis of group members (continued)

Variable	Variance Grouping	AICC	Normality
Reflective			
NASA TLX			
Mental	U	272.4	
	PS	272.6	
	R	**270.5**	**S**
Temporal	U	274.1	
	PS	278.1	
	R	271.1	V
Job Satisfaction			
Challenge			
Results	U	148.2	V
	PS	151.8	
	R	151.6	
Resources			
Information	U	142.1	
	PS	140.3	
	R	**137.0**	**S**
Competent	U	134.2	
	PS	127.5	
	R	125.0	V
Helpful	U	136.3	
	PS	132.7	
	R	**128.3**	**S**
Supplemental Questions			
Liked system	U	196.6	V
	PS	200.7	
	R	199.2	
Excessive work	U	164.1	V
	PS	168.3	
	R	167.4	
Team Workload			
Value of group interaction	U	259.3	
	PS	259.1	
	R	257.2	V
Degree of cooperation	**U**	**268.6**	**S**
	PS	267.3	
	R	269.1	V

Appendix A.10 Variance tables for variables without significant differences

This appendix contains the analysis of variance tables for variables in which no significant effects were found.

A.10.1 Design Performance Variables

Table A. 10.1 ANOVA for cost effectiveness with robustness (transformed: Log10(x+1))

Source	DF	SS	MS	F	P
TD	1	0.00817	0.00817	0.301	0.587
PS	2	0.00520	0.00260	0.096	0.909
TD*PS	2	0.02732	0.1366	0.504	0.609
S/TD*PS	30	0.81345	0.2712		
Total	35	0.85413			

Table A.10.2 ANOVA for cost effectiveness without robustness (transformed: $Log_{10}(x+1)$)

Source	DF	SS	MS	F	P
TD	1	0.00001	0.00001	0.000	0.982
PS	2	0.00534	0.00267	0.093	0.912
TD*PS	2	0.01539	0.00770	0.267	0.767
S/TD*PS	30	0.86454	0.02882		
Total	35	0.88529			

Table A.10.3 ANOVA for system effectiveness

Source	DF	SS	MS	F	P
TD	1	57068.03	57068.03	0.832	0.369
PS	2	23163.64	11581.82	0.169	0.846
TD*PS	2	220200.50	110100.20	1.604	0.218
S/TD*PS	30	2058797.00	68626.57		
Total	35	2359229.17			

Table A. 10.4 ANOVA for system effectiveness without robustness

Source	DF	SS	MS	F	P
TD	1	284445	284445	3.70	0.064
PS	2	15061	7531	0.10	0.907
TD*PS	2	126667	63334	0.82	0.449
S/TD*PS	30	2309258	76975		
Total	35	2735432			

Table A.10.5 ANOVA for robustness

Source	DF	SS	MS	F	P
TD	1	19290	19290	0.88	0.356
PS	2	52407	26204	1.19	0.318
TD*PS	2	13154	65772	2.99	0.065
S/TD*PS	30	659814	21994		
Total	35	863055			

Table A.10.6 ANOVA for system size

Source	DF	SS	MS	F	P
TD	1	1111	1111	0.08	0.781
PS	2	10556	5278	0.37	0.691
TD*PS	2	37222	18611	1.32	0.282
S/TD*PS	30	423333	14111		
Total	35	472222			

Table A.10.7 ANOVA for manufacturing time (producibility)

Source	DF	SS	MS	F	P
TD	1	13611	13611	0.87	0.360
PS	2	11667	5833	0.37	0.693
TD*PS	2	10556	5278	0.34	0.717
S/TD*PS	30	471667	15722		
Total	35	507500			

Table A. 10.8 ANOVA for material costs

Source	DF	SS	MS	F	P
TD	1	36492	36492	1.58	0.219
PS	2	24156	12078	0.52	0.599
TD*PS	2	9033	4516	0.20	0.824
S/TD*PS	30	694165	23139		
Total	35	763846			

Table A.10.9 ANOVA for number of errors

Source	DF	SS	MS	F	P
TD	1	2.250	2.250	0.36	0.555
PS	2	5.056	2.528	0.40	0.674
TD*PS	2	8.167	4.083	0.65	0.531
S/TD*PS	30	189.500	6.317		
Total	35	204.972			

Table A. 10.10 ANOVA for total parts

Source	DF	SS	MS	F	P
TD	1	96.7	96.7	0.41	0.528
PS	2	64.4	32.2	0.14	0.874
TD*PS	2	391.1	195.5	0.82	0.448
S/TD*PS	30	7118.8	237.3		
Total	35	7671.0			

Table A. 10.11 ANOVA for unique parts

Source	DF	SS	MS	F	P
TD	1	12.25	12.25	1.12	0.299
PS	2	19.39	9.69	0.88	0.423
TD*PS	2	3.17	1.58	0.14	0.866
S/TD*PS	30	328.83	10.96		
Total	35	363.64			

Table A. 10.12 ANOVA for number of concepts generated

Source	DF	SS	MS	F	P
TD	1	13.444	13.444	3.27	0.081
PS	2	0.722	0.361	0.09	0.916
TD*PS	2	2.722	1.361	0.33	0.721
S/TD*PS	30	123.333	4.111		
Total	35	140.222			

Table A. 10.13 ANOVA for number of design criteria

Source	DF	SS	MS	F	P
TD	1	3.361	3.361	1.56	0.221
PS	2	1.167	0.583	0.27	0.764
TD*PS	2	3.722	1.861	0.87	0.431
S/TD*PS	30	64.500	2.150		
Total	35	72.750			

A.10.2 Planning Performance Variables

Table A. 10.14 ANOVA for scoping document score

Source	DF	SS	MS	F	P
TD	1	0.000	0.000	0.000	1.000
PS	1	0.667	0.667	0.755	0.395
TD*PS	1	1.500	1.500	1.698	1.698
S/TD*PS	20	17.667	0.883		
Total	23	19.833			

A.10.3 NASA TLX

Planning

Table A. 10.15 ANOVA for NASA TLX during planning

Source	DF	SS	MS	F	P
TD	1	8.194	8.194	1.94	0.179
PS	1	0.226	0.226	0.05	0.819
TD*PS	1	9.947	9.947	2.36	0.140
S/TD*PS	20	84.288	4.214		
Total	23	102.653			

Table A. 10.16 ANOVA for mental demand during planning

Source	DF	SS	MS	F	P
TD	1	9.82	9.82	0.91	0.352
PS	1	8.66	8.66	0.80	0.381
TD*PS	1	0.05	0.05	0.00	0.947
S/TD*PS	20	215.87	10.79		
Total	23	234.39			

Table A. 10.17 ANOVA for physical demand during planning (transformed with $Log_{10}(x+1)$)

Source	DF	SS	MS	F	P
TD	1	0.0000	0.0000	0.00	0.994
PS	1	0.0665	0.0665	1.16	0.294
TD*PS	1	0.0025	0.0025	0.04	0.837
S/TD*PS	20	1.1466	0.0573		
Total	23	1.2156			

Table A. 10.18 ANOVA for temporal demand during planning

Source	DF	SS	MS	F	P
TD	1	23.66	23.66	1.16	0.295
PS	1	3.18	3.18	0.16	0.698
TD*PS	1	67.16	67.16	3.28	0.085
S/TD*PS	20	409.73	20.49		
Total	23	503.73			

Table A. 10.19 ANOVA for performance during planning

Source	DF	SS	MS	F	P
TD	1	11.860	11.860	1.22	0.283
PS	1	37.281	37.281	3.83	0.065
TD*PS	1	30.612	30.612	3.14	0.092
S/TD*PS	20	194.85	9.743		
Total	23	274.604			

Table A. 10.20 ANOVA for effort during planning

Source	DF	SS	MS	F	P
TD	1	28.15	28.15	2.46	0.133
PS	1	9.38	9.38	0.82	0.377
TD*PS	1	17.71	17.71	1.54	0.228
S/TD*PS	20	229.33	11.47		
Total	23	284.56			

Table A. 10.21 ANOVA for frustration during planning

Source	DF	SS	MS	F	P
TD	1	87.81	87.81	3.98	0.060
PS	1	15.61	15.61	0.71	0.410
TD*PS	1	0.02	0.02	0.00	0.978
S/TD*PS	20	441.07	22.05		
Total	23	544.51			

Design Process

Table A. 10.22 ANOVA for performance during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.17	0.6821
PS	Fixed	2		2.09	0.1345
TD*PS	Fixed	2		2.91	0.0638
s/PS*TD	Random	50	1.4446		
Within					
DP	Fixed	2		0.48	0.6254
DP*TD	Fixed	2		0.20	0.8202
DP*PS	Fixed	4		0.68	0.6136
DP*TD*PS	Fixed	4		0.51	0.7262
Residual G	Random	22	2.3452		
Residual I	Random	22	22.5600		

Reflective

Table A. 10.23 ANOVA for the reflective NASA TLX

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		0.58	0.4551
PS	Fixed	2		1.65	0.2150
TD*PS	Fixed	2		1.60	0.2248
Residual G	Random	23	1.1546		
Residual I	Random	23	4.2414		

Table A. 10.24 ANOVA for the reflective mental demand

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		1.22	0.2817
PS	Fixed	2		2.22	0.1377
TD*PS	Fixed	2		0.49	0.6212
Residual A	Random		3.9811		
Residual M	Random		9.0265		
Residual N	Random		17.4653		

Table A. 10.25 ANOVA for the reflective physical demand

Source	DF	SS	MS	F	P
TD	1	35.38	35.38	1.24	0.274
PS	2	1.18	0.59	0.02	0.980
TD*PS	2	95.52	47.76	1.68	0.204
s/TD*PS	30	855.16	28.51		
Total	35	987.25			

Table A. 10.26 ANOVA for the reflective temporal demand

Source	DF	SS	MS	F	P
TD	1	32.99	32.99	2.53	0.122
PS	2	4.11	2.06	0.16	0.855
TD*PS	2	7.57	3.78	0.29	0.750
s/TD*PS	30	390.48	13.02		
Total	35	435.14			

Table A. 10.27 ANOVA for the reflective performance

Source	DF	SS	MS	F	P
TD	1	2.87	2.87	0.26	0.615
PS	2	11.82	5.91	0.53	0.592
TD*PS	2	14.60	7.30	0.66	0.525
s/TD*PS	30	332.73	11.09		
Total	35	362.02			

Table A. 10.28 ANOVA for the reflective effort

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.41	0.5295
PS	Fixed	2		0.76	0.4779
TD*PS	Fixed	2		2.31	0.1209
Residual G	Random	24	4.4594		
Residual I	Random	24	13.3418		

A.10.4 Job Satisfaction

Planning

Table A. 10.29 ANOVA for job satisfaction during planning

Source	DF	SS	MS	F	P
TD	1	78.243	78.243	1.602	0.220
PS	1	104.158	104.158	2.132	0.160
TD*PS	1	0.166	0.166	0.003	0.954
S/TD*PS	20	976.905	48.845		
Total	23	1159.472			

Table A. 10.30 ANOVA for comfort during planning

Source	DF	SS	MS	F	P
TD	1	5.999	5.999	0.860	0.365
PS	1	10.665	10.665	1.530	0.230
TD*PS	1	0.167	0.167	0.024	0.879
S/TD*PS	20	139.442	6.972		
Total	23	156.272			

Table A. 10.31 ANOVA for excessive work during planning

Source	DF	SS	MS	F	P
TD	1	2.042	2.042	1.57	0.225
PS	1	1.042	1.042	0.80	0.382
TD*PS	1	0.042	0.042	0.03	0.860
S/TD*PS	20	26.055	1.303		
Total	23	29.180			

Table A. 10.32 ANOVA for physical surroundings during planning

Source	DF	SS	MS	F	P
TD	1	2.2407	2.2407	3.68	0.070
PS	1	0.6667	0.6667	1.09	0.038
TD*PS	1	0.0000	0.0000	0.00	1.00
S/TD*PS	20	12.1852	0.6093		
Total	23	15.0926			

Table A. 10.33 ANOVA for personal problems during planning

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		0.00	0.9601
PS	Fixed	1		0.31	0.5842
TD*PS	Fixed	1		0.31	0.5842
Residual G	Random	14	0.6759		
Residual I	Random	14	2.9000		

Table A. 10.34 ANOVA for challenge during planning

Source	DF	SS	MS	F	P
TD	1	12.042	12.042	0.949	0.342
PS	1	35.037	35.037	2.761	0.112
TD*PS	1	0.376	0.376	0.030	0.865
S/TD*PS	20	253.816	12.691		
Total	23	301.270			

Table A. 10.35 ANOVA for develop ability during planning

Source	DF	SS	MS	F	P
TD	1	0.5602	0.5602	0.78	0.387
PS	1	2.8935	2.8935	4.04	0.058
TD*PS	1	0.1157	0.1157	0.16	0.692
S/TD*PS	20	14.3148	0.7157		
Total	23	17.8843			

Table A. 10.36 ANOVA for problem interest during planning

Source	DF	SS	MS	F	P
TD	1	0.296	0.296	0.16	0.696
PS	1	1.852	1.852	0.99	0.333
TD*PS	1	0.019	0.019	0.01	0.922
S/TD*PS	20	37.593	1.880		
Total	23	39.759			

Table A. 10.37 ANOVA for freedom during planning

Source	DF	SS	MS	F	P
TD	1	1.852	1.852	1.83	0.191
PS	1	2.241	2.241	2.21	0.153
TD*PS	1	0.019	0.019	0.02	0.894
S/TD*PS	20	20.259	1.013		
Total	23	24.370			

Table A. 10.38 ANOVA for problem difficulty during planning

Source	DF	SS	MS	F	P
TD	1	0.116	0.116	0.11	0.748
PS	1	0.116	0.116	0.11	0.748
TD*PS	1	0.116	0.116	0.11	0.748
S/TD*PS	20	21.759	1.088		
Total	23	22.106			

Table A. 10.39 ANOVA for ability to see work results during planning

Source	DF	SS	MS	F	P
TD	1	2.449	2.449	1.67	0.211
PS	1	1.042	1.042	0.71	0.409
TD*PS	1	0.375	0.375	0.26	0.619
S/TD*PS	20	29.352	1.468		
Total	23	33.218			

Table A. 10.40 ANOVA for resources during planning

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		2.39	0.1452
PS	Fixed	1		0.29	0.5987
TD*PS	Fixed	1		0.11	0.7513
Residual G	Random	14	1.1627		
Residual I	Random	14	6.0167		

Table A. 10.41 ANOVA for access to proper equipment during planning

Source	DF	SS	MS	F	P
TD	1	0.463	0.463	0.831	0.373
PS	1	1.851	1.851	3.321	0.083
TD*PS	1	0.019	0.019	0.033	0.857
S/TD*PS	20	11.149	0.557		
Total	23	13.482			

Table A. 10.42 ANOVA for information during planning

Source	DF	SS	MS	F	P
TD	1	1.1852	1.1852	2.66	0.119
PS	1	0.0185	0.0185	0.04	0.841
TD*PS	1	0.0741	0.0741	0.17	0.688
S/TD*PS	20	8.9259	0.4463		
Total	23	10.2037			

Table A. 10.43 ANOVA for responsibility during planning (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
TD	1	0.02714	0.02714	1.92	0.182
PS	1	0.00000	0.00000	0.00	0.994
TD*PS	1	0.00040	0.00040	0.03	0.869
S/TD*PS	20	0.28343	0.01417		
Total	23	0.31097			

Design Process

Table A. 10.44 ANOVA for ability to forget personal problems during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.92	0.3442
PS	Fixed	2		0.28	0.7600
TD*PS	Fixed	2		0.38	0.6883
s/PS*TD	Random	29	1.3162		
Within					
DP	Fixed	2		1.57	0.2208
DP*TD	Fixed	2		0.41	0.6668
DP*PS	Fixed	4		1.77	0.1550
DP*TD*PS	Fixed	4		0.54	0.7049
Residual A	Random	18	0.3841		
Residual M	Random	20	0.0751		
Residual N	Random	20	0.1134		

Table A. 10.45 ANOVA for challenge during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.06	0.8023
PS	Fixed	2		0.29	0.7532
TD*PS	Fixed	2		2.08	0.1406
s/PS*TD	Random	33	3.8050		
Within					
DP	Fixed	2		2.17	0.1295
DP*TD	Fixed	2		0.12	0.8853
DP*PS	Fixed	4		0.64	0.6338
DP*TD*PS	Fixed	4		0.46	0.7631
Residual CD	Random	14	3.0938		
Residual PD	Random	10	2.5120		
Residual DD	Random	24	9.7749		

Table A. 10.46 ANOVA for resources during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.27	0.6107
PS	Fixed	2		0.05	0.9511
TD*PS	Fixed	2		1.63	0.2155
s/PS*TD	Random	26	2.5949		
Within					
DP	Fixed	2		1.12	0.3403
DP*TD	Fixed	2		1.28	0.2931
DP*PS	Fixed	4		0.35	0.8444
DP*TD*PS	Fixed	4		0.73	0.5794
Residual G	Random	31	0.9159		
Residual I	Random	31	5.2890		
DP*TD*PS	Fixed	4		0.85	0.4972
DP*s/PS*TD	Random	58	1.2410		

Table A. 10.47 ANOVA for access to information during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		1.79	0.1896
PS	Fixed	2		0.13	0.8745
TD*PS	Fixed	2		1.89	0.1655
s/PS*TD	Random	35	0.3622		
Within					
DP	Fixed	2		2.23	0.1230
DP*TD	Fixed	2		0.39	0.6829
DP*PS	Fixed	4		0.39	0.8114
DP*TD*PS	Fixed	4		0.43	0.7880
Residual G	Random	33	0.3055		
Residual I	Random	33	1.9397		

Table A. 10.48 ANOVA for responsibility during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.02	0.8938
PS	Fixed	2		0.16	0.8548
TD*PS	Fixed	2		1.94	0.1662
s/PS*TD	Random	24	0.3394		
Within					
DP	Fixed	2		0.29	0.7494
DP*TD	Fixed	2		0.51	0.6057
DP*PS	Fixed	4		0.14	0.9647
DP*TD*PS	Fixed	4		0.76	0.5599
Residual G	Random	30	0.1358		
Residual I	Random	30	0.6553		

Reflective

Table A. 10.49 ANOVA for reflective job satisfaction

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		1.10	0.3055
PS	Fixed	2		0.02	0.9812
TD*PS	Fixed	2		0.95	0.4028
Residual G	Random	23	33.9472		
Residual I	Random	23	122.6800		

Table A. 10.50 ANOVA for reflective comfort

Source	DF	SS	MS	F	P
TD	1	18.299	18.299	1.339	0.256
PS	2	0.173	0.0864	0.006	0.994
TD*PS	2	13.802	6.901	0.505	0.609
S/TD*PS	30	410.130	13.671		
Total	35	442.404			

Table A. 10.51 ANOVA for the reflective perception of excessive work

Source	Effect	DF	MS	F	P
TD	Fixed	1		2.20	0.1526
PS	Fixed	2		0.23	0.7930
TD*PS	Fixed	2		0.94	0.4051
Residual G	Random	22	0.5377		
Residual I	Random	22	2.3333		

Table A. 10.52 ANOVA for reflective physical surroundings

Source	DF	SS	MS	F	P
TD	1	0.1111	0.1111	0.24	0.630
PS	2	0.0556	0.0278	0.06	0.943
TD*PS	2	2.3889	1.1944	2.54	0.096
S/TD*PS	30	14.1111	0.4704		
Total	35	16.6667			

Table A. 10.53 ANOVA for reflective perception of time

Source	DF	SS	MS	F	P
TD	1	0.890	0.890	0.26	0.617
PS	2	0.826	0.413	0.12	0.889
TD*PS	2	1.893	0.946	0.27	0.764
s/PS*TD	30	104.449	3.482		
Total	35	108.057			

Table A. 10.54 ANOVA for reflective personal problems

Source	Effect	DF	Variance Component	F value	Probability
TD	Fixed	1		2.10	0.1630
PS	Fixed	2		0.19	0.8308
TD*PS	Fixed	2		0.17	0.8488
Residual G	Random	20	0.4753		
Residual I	Random	20	2.9222		

Table A. 10.55 ANOVA for reflective challenge

Source	DF	SS	MS	F	P
TD	1	4.938	4.938	0.432	0.516
PS	2	0.0803	0.040	0.004	0.996
TD*PS	2	31.673	15.836	1.386	0.266
S/TD*PS	30	342.889	11.430		
Total	35	379.580			

Table A. 10.56 ANOVA for reflective problem interest

Source	Effect	DF	Variance Component	F Value	Probability
TD	Fixed	1		0.00	0.9451
PS	Fixed	2		0.68	0.5190
TD*PS	Fixed	2		2.14	0.1479
Residual A	Random	10	1.5370		
Residual M	Random	10	0.2093		
Residual N	Random	10	0.1444		

Table A. 10.57 ANOVA for reflective freedom

Source	Effect	DF	Variance Component	F Value	Probability
TD	Fixed	1		0.39	0.5415
PS	Fixed	2		0.45	0.6413
TD*PS	Fixed	2		1.51	0.2449
Residual G	Random	20	0.4272		
Residual I	Random	20	2.2778		

Table A. 10.58 ANOVA for reflective problem difficulty

Source	Effect	DF	Variance Component	F Value	Probability
TD	Fixed	1		0.61	0.4437
PS	Fixed	2		0.63	0.5416
TD*PS	Fixed	2		1.71	0.2030
Residual G	Random	23	0.1901		
Residual I	Random	23	0.6333		

Table A. 10.59 ANOVA for reflective ability to see work results

Source	DF	SS	MS	F	P
TD	1	0.0494	0.0494	0.07	0.792
PS	2	0.0432	0.0216	0.03	0.970
TD*PS	2	0.0432	0.0216	0.03	0.970
S/TD*PS	30	20.9259	0.6975		
Total	35	21.0617			

Table A. 10.60 ANOVA for reflective resources

Source	DF	SS	MS	F	P
TD	1	7.716	7.716	1.213	0.279
PS	2	1.710	0.855	0.134	0.875
TD*PS	2	8.784	4.392	0.691	0.509
S/TD*PS	30	190.778	6.359		
Total	35	208.988			

Table A. 10.61 ANOVA for the reflective access to the appropriate equipment

Source	Effect	DF	MS	F	P
TD	Fixed	1		1.07	0.3146
PS	Fixed	2		0.07	0.9370
TD*PS	Fixed	2		0.46	0.6398
Residual G	Random	19	0.0307		
Residual I	Random	19	2.2444		

Table A. 10.62 ANOVA for the reflective access to the information

Source	Effect	DF	MS	F	P
TD	Fixed	1		1.00	0.3275
PS	Fixed	2		0.73	0.4917
TD*PS	Fixed	2		1.29	0.2949
Residual G	Random	23	0.4420		
Residual I	Random	23	1.5556		

Table A. 10.63 ANOVA for the reflective responsibility

Source	Effect	DF	MS	F	P
TD	Fixed	1		0.41	0.5302
PS	Fixed	2		0.08	0.9194
TD*PS	Fixed	2		0.17	0.8487
Residual G	Random	19	0.2395		
Residual I	Random	19	1.5889		

Job Satisfaction with Group Questions

Table A. 10.64 ANOVA for job satisfaction including group questions during planning

Source	DF	SS	MS	F	P
PS	1	57.79	57.79	2.26	0.163
S/PS	15	255.20	25.52		
Total	11	312.99			

Table A. 10.65 ANOVA for job satisfaction including group questions groups during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		2.94	0.0836
S/PS	Random	15	23.0998		
Within					
DP	Fixed	2	32.354	2.70	0.0833
DP*PS	Fixed	4	3.218	0.27	0.8949
DP*S/PS	Random	30	11.9702		

Table A. 10.66 ANOVA for retrospective job satisfaction including group questions

Source	DF	SS	MS	F	P
PS	2	85.481	42.741	0.956	0.406
S/PS	15	670.296	44.686		
Total	17	755.778			

A.10.5 Design Related Questions

Reflective

Table A. 10.67 ANOVA for designing the best system possible

Source	DF	SS	MS	F	P
TD	1	1.000	1.000	0.48	0.493
PS	2	13.019	6.510	3.14	0.058
TD*PS	2	0.908	0.454	0.22	0.805
s/PS*TD	30	62.190	2.073		
Total	35	77.117			

Table A. 10.68 ANOVA for how well participants liked their system

Source	DF	SS	MS	F	P
TD	1	3.567	3.567	1.67	0.207
PS	2	0.692	0.346	0.16	0.852
TD*PS	2	0.469	0.235	0.11	0.897
s/PS*TD	30	64.263	2.142		
Total	35	68.991			

Table A. 10.69 ANOVA for how well the participants met their design objectives

Source	DF	SS	MS	F	P
TD	1	0.197	0.197	0.07	0.797
PS	2	12.526	6.263	2.15	0.134
TD*PS	2	9.673	4.836	1.66	0.207
s/PS*TD	30	87.484	2.916		
Total	35	109.880			

A.10.6 Planning Related Questions

Planning

Table A. 10.70 ANOVA for the ease of use of project support during planning

Source	DF	SS	MS	F	P
TD	1	2.0411	2.0411	2.91	0.103
PS	1	2.8933	2.8933	4.13	0.056
TD*PS	1	1.6711	1.6711	2.38	0.138
S/TD*PS	20	14.0179	0.7009		
Total	23	20.6234			

Table A. 10.71 ANOVA for the efficiency of project support during planning

Source	DF	SS	MS	F	P
TD	1	0.375	0.375	0.25	0.622
PS	1	1.042	1.042	0.70	0.413
TD*PS	1	2.042	2.042	1.37	0.256
S/TD*PS	20	29.834	1.492		
Total	23	33.293			

Table A. 10.72 ANOVA for the effectiveness of project support during planning

Source	DF	SS	MS	F	P
TD	1	0.0416	0.0416	0.05	0.821
PS	1	0.1155	0.1155	0.15	0.707
TD*PS	1	1.3372	1.3372	1.68	0.21
S/TD*PS	20	15.9077	0.7954		
Total	23	17.4020			

Table A. 10.73 ANOVA for the productivity during planning

Source	DF	SS	MS	F	P
TD	1	0.042	0.042	0.03	0.857
PS	1	1.339	1.339	1.08	0.311
TD*PS	1	1.339	1.339	1.08	0.311
S/TD*PS	20	24.795	1.240		
Total	23	27.514			

Table A. 10.74 ANOVA for satisfaction with project support during planning

Source	DF	SS	MS	F	P
TD	1	1.186	1.186	1.13	0.301
PS	1	4.168	4.168	3.96	0.061
TD*PS	1	0.667	0.667	0.63	0.436
S/TD*PS	20	21.073	1.054		
Total	23	27.094			

Table A. 10.75 ANOVA for developing the best plan possible

Source	DF	SS	MS	F	P
TD	1	0.907	0.907	0.82	0.377
PS	1	1.853	1.853	1.66	0.212
TD*PS	1	3.131	3.131	2.81	0.109
S/TD*PS	20	22.26	1.113		
Total	23	28.151			

Design Process

Table A. 10.76 ANOVA for the efficiency of the project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		0.36	0.5550
PS	Fixed	2		0.48	0.4942
TD*PS	Fixed	2		0.00	0.9810
s/TD*PS	Random	20	0.7062		
Within					
DP	Fixed	2		0.14	0.8735
DP*TD	Fixed	2		1.10	0.3429
DP*PS	Fixed	4		0.60	0.5532
DP*TD*PS	Fixed	4		0.97	0.3889
DP*S/TD*PS	Random	40	0.5571		

Table A. 10.77 ANOVA for the effectiveness of the project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		1.90	0.1829
PS	Fixed	2		0.77	0.3905
TD*PS	Fixed	2		0.03	0.8624
s/TD*PS	Random	20	0.6185		
Within					
DP	Fixed	2		0.59	0.5585
DP*TD	Fixed	2		2.00	0.1486
DP*PS	Fixed	4		0.56	0.5757
DP*TD*PS	Fixed	4		0.64	0.5338
DP*S/TD*PS	Random	40	0.5979		

Table A. 10.78 ANOVA for the productivity of the project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		1.11	0.3027
PS	Fixed	2		1.23	0.2803
TD*PS	Fixed	2		0.11	0.7411
s/TD*PS	Random	22	0.3433		
Within					
DP	Fixed	2		0.03	0.9707
DP*TD	Fixed	2		1.14	0.3314
DP*PS	Fixed	4		0.52	0.5983
DP*TD*PS	Fixed	4		0.15	0.854
Residual G	Random	33	0.7271		
Residual I	Random	33	1.8691		

Table A. 10.79 ANOVA for the satisfaction with using the of the project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
TD	Fixed	1		2.12	0.1571
PS	Fixed	2		3.67	0.0661
TD*PS	Fixed	2		0.05	0.8200
s/TD*PS	Random	27	0.5800		
Within					
DP	Fixed	2		0.30	0.7424
DP*TD	Fixed	2		0.50	0.6147
DP*PS	Fixed	4		1.24	0.3081
DP*TD*PS	Fixed	4		0.32	0.7319
Residual CD	Random	24	0.03749		
Residual PD	Random	24	0.7362		
Residual DD	Random	24	1.1070		

Reflective

Table A. 10.80 ANOVA for the reflective satisfaction with project support tools

Source	DF	SS	MS	F	P
TD	1	0.116	0.116	0.08	0.781
PS	1	1.671	1.671	1.15	0.296
TD*PS	1	0.782	0.782	0.54	0.471
S/TD*PS	20	28.980	1.449		
Total	23	31.549			

Table A. 10.81 ANOVA for the reflective productivity with project support tools

Source	DF	SS	MS	F	P
TD	1	0.116	0.116	0.06	0.802
PS	1	0.560	0.560	0.31	0.582
TD*PS	1	1.337	1.337	0.75	0.397
S/TD*PS	20	35.759	1.788		
Total	23	37.771			

Table A. 10.82 ANOVA for the ability to stay on schedule

Source	DF	SS	MS	F	P
TD	1	0.116	0.116	0.04	0.838
PS	1	0.227	0.227	0.08	0.775
TD*PS	1	0.226	0.226	0.04	0.838
S/TD*PS	20	54.091	2.705		
Total	23	54.549			

Table A. 10.83 ANOVA for the ability to stay on budget

Source	DF	SS	MS	F	P
TD	1	0.227	0.227	0.11	0.744
PS	1	0.375	0.375	0.18	0.675
TD*PS	1	0.042	0.042	0.02	0.889
S/TD*PS	20	41.353	2.068		
Total	23	41.997			

Appendix A.11 MANOVA Tables

A.11.1 Design Performance

Table A. 11.1 MANOVA on reliability, robustness, system size, and producibility

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.622	4.111	4	27	0.010*
Hotelling	0.609	4.111	4	27	0.010*
Pillai	0.378	4.111	4	27	0.010*
Project Support					
Wilks	0.819	0.707	8	54	0.684
Hotelling	0.215	0.697	8	52	0.692
Pillai	0.185	0.715	8	56	0.677
Team Design * Project Support					
Wilks	0.744	1.074	8	54	0.395
Hotelling	0.328	1.065	8	52	0.401
Pillai	0.268	1.081	8	56	0.390

*p<0.05

Table A. 11.2 MANOVA on material cost, design cost, and lifecycle cost

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.071	121.76	3	28	<0.0001***
Hotelling	13.046	121.76	3	28	<0.0001***
Pillai	0.929	121.76	3	28	<0.0001***
Project Support					
Wilks	0.531	3.477	6	56	0.005**
Hotelling	0.788	3.546	6	54	0.005**
Pillai	0.520	3.398	6	58	0.006**
Team Design * Project Support					
Wilks	0.858	0.741	6	56	0.619
Hotelling	0.163	0.733	6	54	0.625
Pillai	0.144	0.748	6	58	0.613

***p<0.01
***p<0.001

Table A. 11.3 MANOVA on total parts, number of moving parts, and number of unique parts

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.784	2.574	3	28	0.074
Hotelling	0.276	2.574	3	28	0.074
Pillai	0.216	2.574	3	28	0.074
Project Support					
Wilks	0.799	1.106	6	56	0.371
Hotelling	0.238	1.073	6	54	0.390
Pillai	0.211	1.137	6	58	0.352
Team Design * Project Support					
Wilks	0.767	1.322	6	56	0.263
Hotelling	0.286	1.287	6	54	0.279
Pillai	0.246	1.356	6	58	0.248

*p<0.05

Table A. 11.4 MANOVA on number of concepts and design criteria

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.874	2.092	2	29	0.142
Hotelling	0.144	2.092	2	29	0.142
Pillai	0.126	2.092	2	29	0.142
Project Support					
Wilks	0.974	0.194	4	58	0.940
Hotelling	0.027	0.189	4	56	0.943
Pillai	0.026	0.200	4	60	0.938
Team Design * Project Support					
Wilks	0.932	0.520	4	58	0.721
Hotelling	0.073	0.510	4	56	0.729
Pillai	0.068	0.530	4	60	0.714

*p<0.05

Table A. 11.5 MANOVA on number of scoping and Gantt chart scores

Source	Test Statistic	F	DF		P
Team Design					
Wilks	1.000	0.000	2	19	1.000
Hotelling	0.000	0.000	2	19	1.000
Pillai	0.000	0.000	2	19	1.000
Project Support					
Wilks	0.403	14.078	2	19	<0.0001*
Hotelling	1.482	14.078	2	19	<0.0001*
Pillai	0.597	14.078	2	19	<0.0001*
Team Design * Project Support					
Wilks	0.906	0.984	2	19	0.392
Hotelling	0.104	0.984	2	19	0.392
Pillai	0.094	0.984	2	19	0.392

*p<0.05

A.11.2 NASA TLX Components

Planning

Table A. 11.6 MANOVA on mental, physical, and temporal demand, performance, effort, and frustration during planning

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.522	2.285	6	15	0.091
Hotelling	0.914	2.285	6	15	0.091
Pillai	0.478	2.285	6	15	0.091
Project Support					
Wilks	0.519	2.316	6	15	0.088
Hotelling	0.926	2.316	6	15	0.088
Pillai	0.481	2.316	6	15	0.088
Team Design * Project Support					
Wilks	0.584	1.778	6	15	0.171
Hotelling	0.711	1.778	6	15	0.171
Pillai	0.416	1.778	6	15	0.171

Design Process

Table A. 11.7 MANOVA on mental, physical, and temporal demand, performance, effort, and frustration during design

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.896	0.48	6	25	0.139
Hotelling	0.116	0.48	6	25	0.139
Pillai	0.104	0.48	6	25	0.139
Project Support					
Wilks	0.791	0.52	12	50	0.8924
Hotelling	0.249	0.51	12	36	0.8972
Pillai	0.221	0.54	12	52	0.8785
Design Phase					
Wilks	0.244	9.40	12	110	<0.0001*
Hotelling	2.729	12.35	12	83	<0.0001*
Pillai	0.848	6.87	12	112	<0.0001*
Team Design * Project Support					
Wilks	0.776	0.56	12	50	0.8616
Hotelling	0.276	0.56	12	36	0.8593
Pillai	0.233	0.57	12	52	0.8545
Team Design * Design Phase					
Wilks	0.672	2.01	12	110	0.0295*
Hotelling	0.458	2.07	12	82	0.0276*
Pillai	0.347	1.96	12	112	0.0345*
Project Support * Design Phase					
Wilks	0.558	1.47	24	193	0.0824
Hotelling	0.665	1.49	24	122	0.0819
Pillai	0.517	1.44	24	232	0.0919
Team Design * Project Support * Design Phase					
Wilks	6.55	1.04	24	193	0.4225
Hotelling	0.466	1.05	24	122	0.4152
Pillai	0.386	1.03	24	232	0.4270

*p<0.05

Reflective

Table A. 11.8 MANOVA on reflective mental, physical, and temporal demand, performance, effort, and frustration

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.703	1.761	6	25	0.148
Hotelling	0.423	1.761	6	25	0.148
Pillai	0.297	1.761	6	25	0.148
Project Support					
Wilks	0.796	0.503	12	50	0.903
Hotelling	0.243	0.487	12	48	0.918
Pillai	0.214	0.519	12	52	0.893
Team Design * Project Support					
Wilks	0.730	0.710	12	50	0.734
Hotelling	0.346	0.693	12	48	0.750
Pillai	0.287	0.726	12	52	0.719

A.11.3 Job Satisfaction Components

Planning

Table A. 11.9 MANOVA on comfort, challenge, and resources during planning

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.893	0.721	3	18	0.553
Hotelling	0.120	0.721	3	18	0.553
Pillai	0.107	0.721	3	18	0.553
Project Support					
Wilks	0.825	1.270	3	18	0.315
Hotelling	0.212	1.270	3	18	0.315
Pillai	0.175	1.270	3	18	0.315
Team Design * Project Support					
Wilks	0.980	0.119	3	18	0.948
Hotelling	0.980	0.119	3	18	0.948
Pillai	0.980	0.119	3	18	0.948

Table A. 11.10 MANOVA on all questions used to calculate job satisfaction during planning

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.460	0.882	12	9	0.590
Hotelling	1.176	0.882	12	9	0.590
Pillai	0.540	0.882	12	9	0.590
Project Support					
Wilks	0.468	0.854	12	9	0.610
Hotelling	1.138	0.854	12	9	0.610
Pillai	0.532	0.854	12	9	0.610
Team Design * Project Support					
Wilks	0.624	0.451	12	9	0.900
Hotelling	0.692	0.451	12	9	0.900
Pillai	0.376	0.451	12	9	0.900

Design Process

Table A. 11.11 MANOVA on comfort, challenge, and resources

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.983	0.16	3	28	0.9238
Hotelling	0.0169	0.16	3	28	0.9238
Pillai	0.0166	0.16	3	28	0.9238
Project Support					
Wilks	0.874	0.65	6	56	0.6884
Hotelling	0.142	0.65	6	37	0.6894
Pillai	0.129	0.67	6	58	0.6777
Design Phase					
Wilks	0.551	6.70	6	116	<0.0001*
Hotelling	0.767	7.36	6	76	<0.0001*
Pillai	0.474	6.11	6	118	<0.0001*
Team Design * Project Support					
Wilks	0.866	0.70	6	56	0.6532
Hotelling	0.153	0.70	6	36	0.6489
Pillai	0.136	0.70	6	58	0.6482
Team Design * Design Phase					
Wilks	0.928	0.73	6	116	0.6253
Hotelling	0.0762	0.73	6	76	0.6266
Pillai	0.0724	0.74	6	118	0.6195
Project Support * Design Phase					
Wilks	0.844	0.85	12	154	0.6029
Hotelling	0.178	0.85	12	97	0.6034
Pillai	0.161	0.85	12	180	0.5956
Team Design * Project Support * Design Phase					
Wilks	0.865	0.72	12	154	0.7297
Hotelling	0.149	0.71	12	97	0.7396
Pillai	0.141	0.74	12	180	0.7113

*p<0.05

Table A. 11.12 MANOVA on all questions

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.340	2.69	13	18	0.026*
Hotelling	1.945	2.69	13	18	0.026*
Pillai	0.660				
Project Support					
Wilks	0.294	1.17	26	36	0.3280
Hotelling	1.917	1.27	26	27	0.2675
Pillai	0.848	1.08	26	38	0.4114
Design Phase					
Wilks	0.218	4.22	26	96	<0.0001***
Hotelling	2.750	4.99	26	80	<0.0001***
Pillai	0.964	3.51	26	98	<0.0001***
Team Design * Project Support					
Wilks	0.344	0.98	26	36	0.5194
Hotelling	1.436	0.95	26	27	0.5473
Pillai	0.817	1.01	26	38	0.4086
Team Design * Design Phase					
Wilks	0.526	1.40	26	96	0.1237
Hotelling	0.790	1.43	26	80	0.1336
Pillai	0.531	1.36	26	98	0.1400
Project Support * Design Phase					
Wilks	0.430	0.88	52	188	0.6982
Hotelling	0.980	0.88	52	131	0.6941
Pillai	0.735	0.88	52	204	0.6952
Team Design * Project Support * Design Phase					
Wilks	0.374	1.04	52	188	0.4055
Hotelling	1.153	1.04	52	131	0.4273
Pillai	0.849	1.06	52	204	0.3842

*p<0.05
***p<0.001

<u>Reflective</u>

Table A. 11.13 MANOVA on reflective comfort, challenge, and resources

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.943	0.565	3	28	0.642
Hotelling	0.061	0.565	3	28	0.642
Pillai	0.057	0.565	3	28	0.642
Project Support					
Wilks	0.973	0.126	6	56	0.993
Hotelling	0.027	0.123	6	54	0.993
Pillai	0.027	0.130	6	58	0.992
Team Design * Project Support					
Wilks	0.895	0.532	6	56	0.782
Hotelling	0.116	0.520	6	54	0.791
Pillai	0.106	0.543	6	58	0.774

Table A. 11.14 MANOVA on reflective questions

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.620	0.970	12	19	0.507
Hotelling	0.613	0.970	12	19	0.507
Pillai	0.380	0.970	12	19	0.507
Project Support					
Wilks	0.509	0.637	24	38	0.877
Hotelling	0.834	0.626	24	36	0.885
Pillai	0.558	0.645	24	40	0.872
Team Design * Project Support					
Wilks	0.261	1.518	24	38	0.122
Hotelling	1.937	1.453	24	36	0.152
Pillai	0.974	1.581	24	40	0.098

A.11.4 Supplemental Design Questions

Reflective

Table A. 11.15 MANOVA on reflective design questions (meet objects, best of ability, and liked design)

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.930	0.700	3	28	0.560
Hotelling	0.075	0.700	3	28	0.560
Pillai	0.070	0.700	3	28	0.560
Project Support					
Wilks	0.646	2.282	6	56	0.048*
Hotelling	0.496	2.232	6	54	0.054
Pillai	0.388	2.329	6	58	0.044*
Team Design * Project Support					
Wilks	0.865	0.705	6	56	0.647
Hotelling	0.156	0.702	6	54	0.649
Pillai	0.136	0.705	6	58	0.647

*p<0.05

A.11.5 Supplemental Planning Questions

Planning

Table A. 11.16 MANOVA on best plan, doubt in ability to complete the plan, ease of use, efficiency, effectiveness, productivity, and satisfaction during planning

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.608	1.288	7	14	0.324
Hotelling	0.664	1.288	7	14	0.324
Pillai	0.392	1.288	7	14	0.324
Project Support					
Wilks	0.613	1.264	7	14	0.335
Hotelling	0.632	1.264	7	14	0.335
Pillai	0.387	1.264	7	14	0.335
Team Design * Project Support					
Wilks	0.385	3.200	7	14	0.030*
Hotelling	1.600	3.200	7	14	0.030*
Pillai	0.615	3.200	7	14	0.030*

*p<0.05

Table A. 11.17 MANOVA on equipment, excessive work, and perception of time during planning

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.689	2.704	3	18	0.076
Hotelling	0.451	2.704	3	18	0.076
Pillai	0.311	2.704	3	18	0.076
Project Support					
Wilks	0.724	2.283	3	18	0.114
Hotelling	0.380	2.283	3	18	0.114
Pillai	0.276	2.283	3	18	0.114
Team Design * Project Support					
Wilks	0.959	0.259	3	18	0.854
Hotelling	0.043	0.259	3	18	0.854
Pillai	0.041	0.259	3	18	0.854

Design Process

Table A. 11.18 MANOVA on ease of use, efficiency, effectiveness, productivity, and satisfaction

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.595	2.18	5	16	0.1076
Hotelling	0.682	2.18	5	16	0.1076
Pillai	0.405	2.18	5	16	0.1076
Project Support					
Wilks	0.782	0.89	5	16	0.5107
Hotelling	0.278	0.89	5	16	0.5107
Pillai	0.218	0.89	5	16	0.5107
Design Phase					
Wilks	0.692	1.46	10	72	0.1733
Hotelling	0.421	1.49	10	51	0.1706
Pillai	0.326	1.44	10	74	0.1799
Team Design * Project Support					
Wilks	0.564	2.47	5	16	0.0768
Hotelling	0.772	2.47	5	16	0.0768
Pillai	0.436	2.47	5	16	0.0768
Team Design * Design Phase					
Wilks	0.764	1.04	10	72	0.4217
Hotelling	0.291	1.03	10	51	0.4313
Pillai	0.2493	1.05	10	74	0.4084
Project Support * Design Phase					
Wilks	0.748	1.12	10	72	0.3578
Hotelling	0.326	1.15	10	51	0.3442
Pillai	0.259	1.10	10	74	0.3713
Team Design * Project Support * Design Phase					
Wilks	0.840	0.66	10	72	0.7601
Hotelling	0.185	0.65	10	51	0.7605
Pillai	0.165	0.67	10	74	0.7521

Reflective

Table A. 11.19 MANOVA on reflective supplemental planning questions

Source	Test Statistic	F	DF		P
Team Design					
Wilks	0.022	0.095	4	17	0.983
Hotelling	0.978	0.095	4	17	0.983
Pillai	0.022	0.095	4	17	0.983
Project Support					
Wilks	0.876	0.603	4	17	0.666
Hotelling	0.142	0.603	4	17	0.666
Pillai	0.124	0.603	4	17	0.666
Team Design * Project Support					
Wilks	0.904	0.452	4	17	0.769
Hotelling	0.106	0.452	4	17	0.769
Pillai	0.096	0.452	4	17	0.769

Appendix A.12 Multiple comparisons for three way interactions

Table A. 12.1 Multiple comparisons of the three way interaction for equipment[1]

		cgm	cgn	cia	cim	cin	pga	pgm	pgn	pia	pim	pin	dga
	mean	5.77	5.44	6.17	5.50	6.33	5.67	5.22	5.78	5.83	6.00	5.50	5.72
cga	5.72	0.05	0.28	0.44	0.22	0.61	0.06	0.50	0.05	0.11	0.28	0.22	0.00
cgm	5.77		0.34	0.39	0.28	0.56	0.11	0.56	0.00	0.05	0.22	0.28	0.06
cgn	5.44			0.72	0.06	0.89*	0.22	0.22	0.34	0.39	0.56	0.06	0.28
cia	6.17				0.67	0.17	0.50	0.95*	0.39	0.33	0.17	0.67	0.45
cim	5.50					0.83	0.17	0.28	0.28	0.33	0.50	0.00	0.22
cin	6.33						0.67	1.11*	0.56	0.50	0.33	0.83*	0.61
pga	5.67							0.45	0.11	0.17	0.33	0.17	0.05
pgm	5.22								0.56	0.61	0.78	0.28	0.50
pgn	5.78									0.05	0.22	0.28	0.06
pia	5.83										0.17	0.33	0.11
pim	6.00											0.50	0.28
pin	5.50												0.22

*p<0.05

[1]Where cga=conceptual design group automated, cgm=conceptual design group manual, cgn=conceptual design group none, cia=conceptual design individual automated, cim= conceptual design individual manual, cin=conceptual design individual none, pga=preliminary design group automated, pgm= preliminary design group manual, pgn= preliminary design group none, pia= preliminary design individual automated, pim= preliminary design individual manual, pin= preliminary design individual none, dga=detailed design group automated, dgm= detailed design group manual, dgn= detailed design group none, dia= detailed design individual automated, dim= detailed design individual manual, din= detailed design individual none

Table A.12.1 Multiple comparisons of the three way interaction for equipment (continued)

		dgm	dgn	dia	dim	din
	mean	5.61	6.11	5.50	5.83	5.17
cga	5.72	0.11	0.39	0.22	0.11	0.56
cgm	5.77	0.17	0.33	0.28	0.05	0.61
cgn	5.44	0.17	0.67	0.06	0.39	0.28
cia	6.17	0.56	0.05	0.67	0.33	1.00
cim	5.50	0.11	0.61	0.00	0.33	0.33
cin	6.33	0.72	0.22	0.83	0.50	1.17*
pga	5.67	0.05	0.45	0.17	0.17	0.50
pgm	5.22	0.39	0.89	0.28	0.61	0.05
pgn	5.78	0.17	0.33	0.28	0.05	0.61
pia	5.83	0.22	0.28	0.33	0.00	0.67
pim	6.00	0.39	0.11	0.50	0.17	0.83
pin	5.50	0.11	0.61	0.00	0.33	0.33
dga	5.72	0.11	0.39	0.22	0.11	0.55
dgm	5.61		0.50	0.11	0.22	0.45
dgn	6.11			0.61	0.28	0.95
dia	5.50				0.33	0.33
dim	5.83					0.67

*p<0.05

In each figure, the levels of one factor were held constant while the levels of the other factors changed.

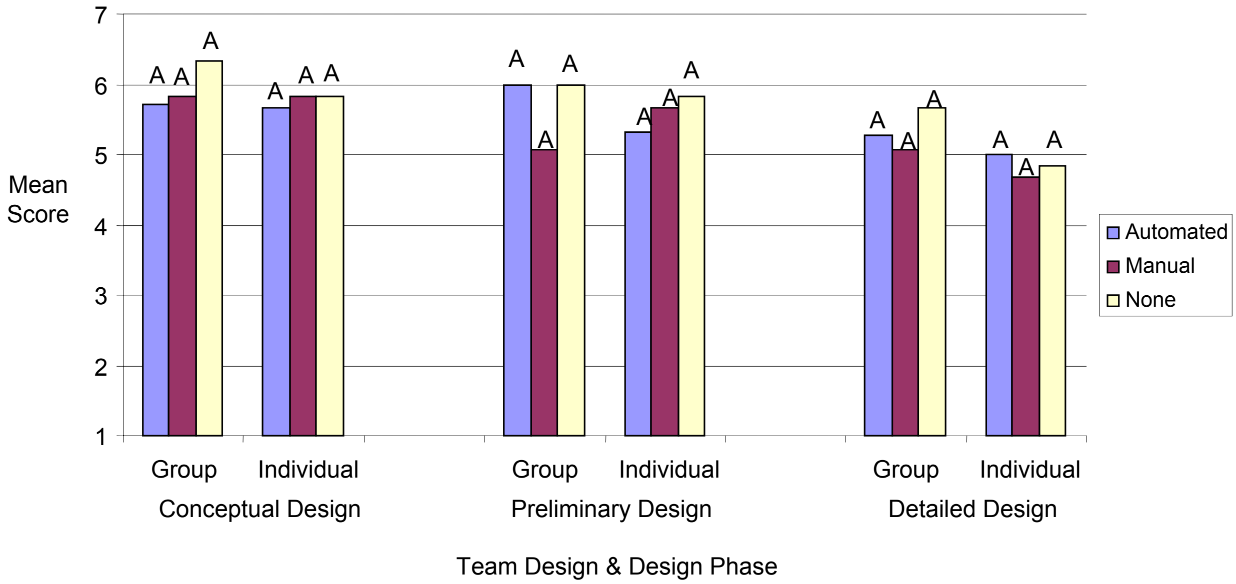


Figure A.12. 1 Comparing mean perceptions of excessive workload in each design phase

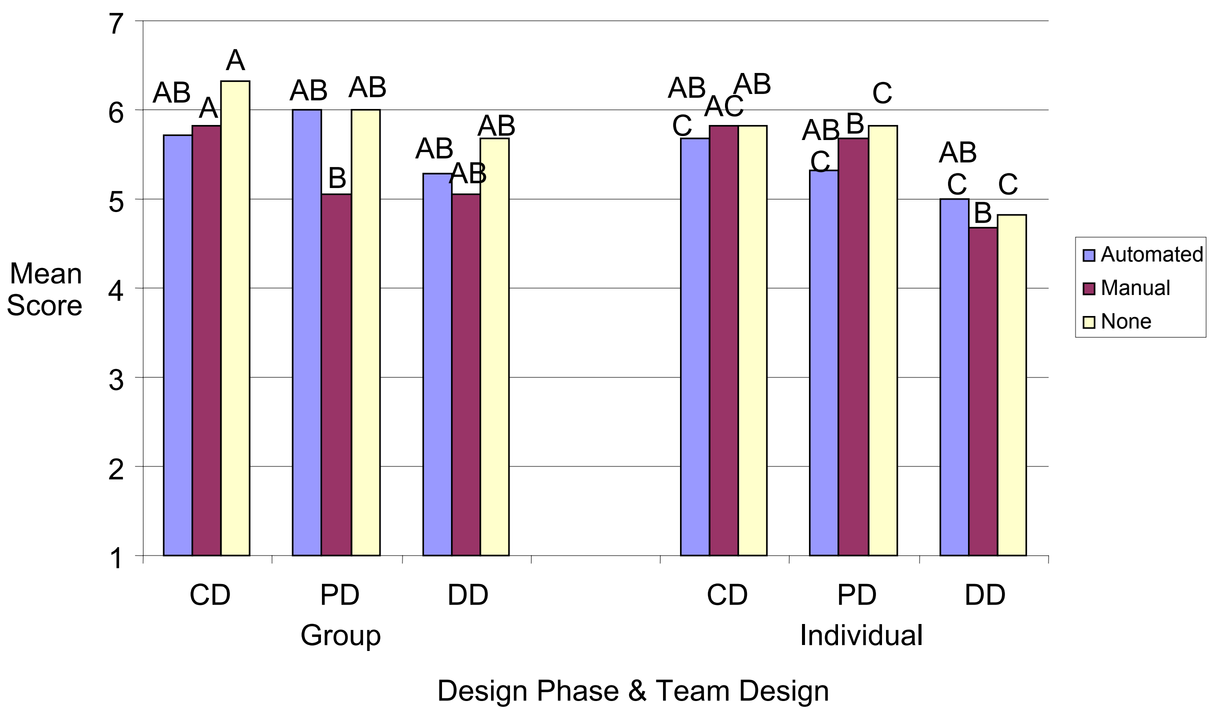


Figure A.12. 2 Comparing mean perceptions of excessive workload within each type of team design (where CD= conceptual design, PD = preliminary design, DD=detailed design)

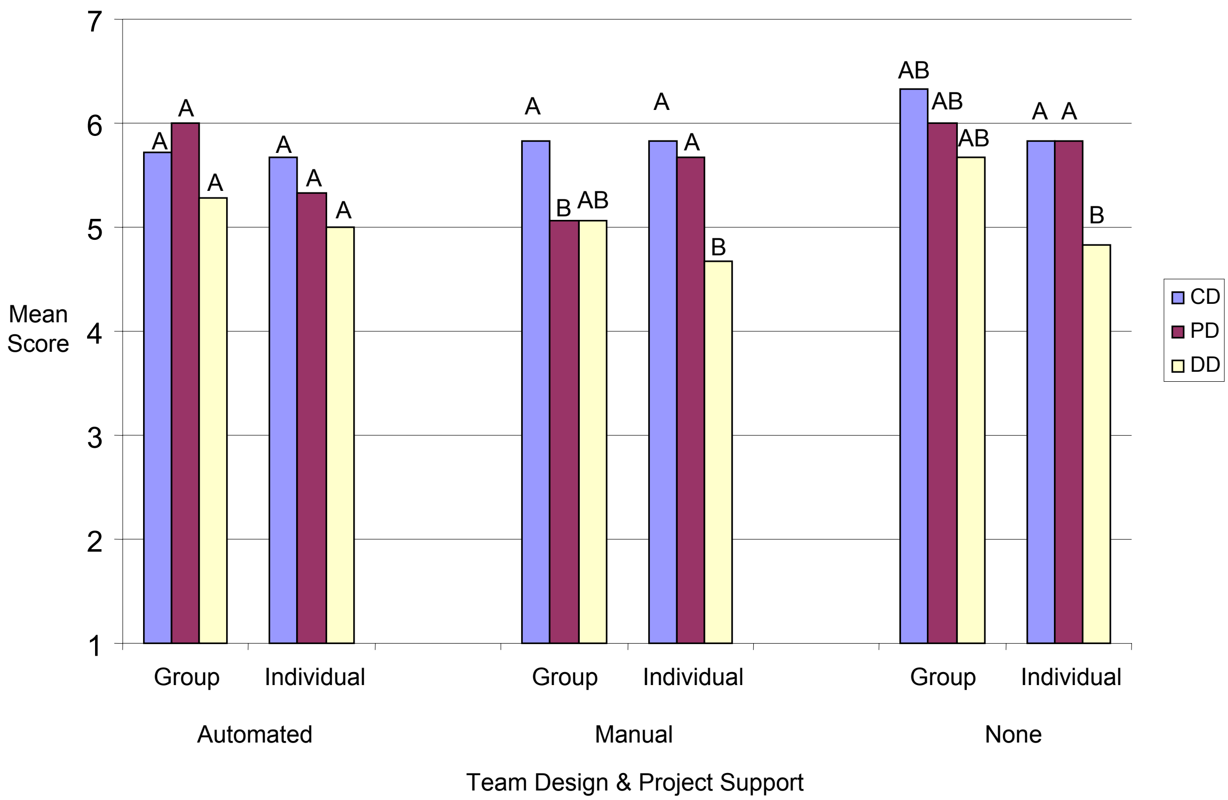


Figure A.12. 3 Comparing mean perceptions of excessive workload within each type of project support

Table A. 12.2 Multiple comparisons of the three way interaction for excessive work

		cgm	cgn	cia	cim	cin	pga	pgm	pgn	pia	pim	pin	dga
	mean	5.83	6.33	5.67	5.83	5.83	6.00	5.06	6.00	5.33	5.67	5.83	5.28
cga	5.72	0.11	0.61	0.06	0.11	0.11	0.28	0.67	0.28	0.39	0.06	0.11	0.44
cgm	5.83		0.50	0.17	0.00	0.00	0.17	0.78*	0.17	0.50	0.17	0.00	0.56
cgn	6.33			0.67	0.50	0.50	0.33	1.28*	0.33	1.00	0.67	0.50	1.06
cia	5.67				0.17	0.17	0.33	0.61	0.33	0.33	0.00	0.17	0.39
cim	5.83					0.00	0.17	0.78	0.17	0.50	0.17	0.00	0.56
cin	5.83						0.17	0.78	0.17	0.50	0.17	0.00	0.56
pga	6.00							0.94	0.00	0.67	0.33	0.17	0.72
pgm	5.06								0.94	0.28	6.11	0.78	0.22
pgn	6.00									0.67	0.33	0.17	0.72
pia	5.33										0.33	0.50	0.06
pim	5.67											0.17	0.39
pin	5.83												0.56

*p<0.05

Table A.12.2 Multiple comparisons of the three way interaction for excessive work (continued)

		dgm	dgn	dia	dim	din
	mean	5.06	5.67	5.00	4.67	4.83
cga	5.72	0.67	0.06	0.72	1.06	0.89
cgm	5.83	0.78	0.17	0.83	1.17*	1.00
cgn	6.33	1.28	0.67	1.33*	1.67*	1.50*
cia	5.67	0.61	0.00	0.67	1.00	0.83
cim	5.83	0.78	0.17	0.83	1.17*	1.00
cin	5.83	0.78	0.17	0.83	1.17	1.00*
pga	6.00	0.94	0.33	1.00	1.33*	1.17
pgm	5.06	0.00	0.61	0.06	0.39	0.22
pgn	6.00	0.94	0.33	1.00	1.33*	1.17
pia	5.33	0.28	0.33	0.33	0.67	0.50
pim	5.67	0.61	0.00	0.67	1.00*	0.83
pin	5.83	0.78	0.17	0.83	1.17	1.00*
dga	5.28	0.22	0.39	0.28	0.61	0.44
dgm	5.06		0.61	0.06	0.39	0.22
dgn	5.67			0.67	1.00	0.83
dia	5.00				0.33	0.17
dim	4.67					0.17

*p<0.05

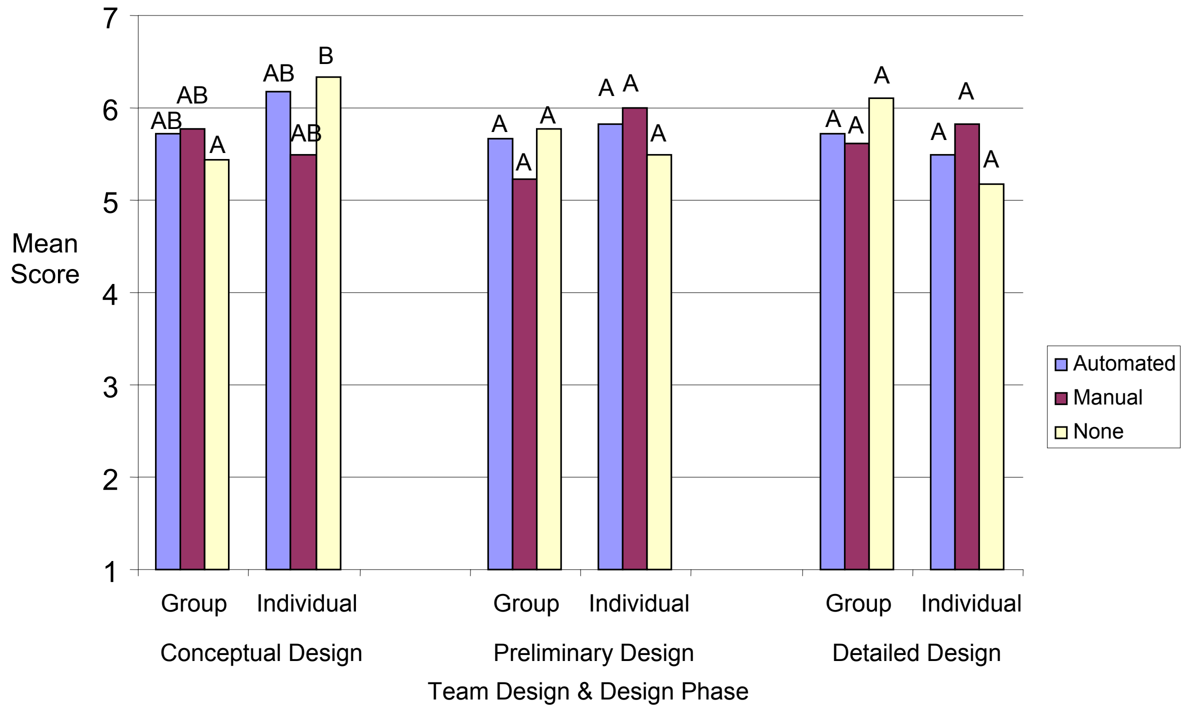


Figure A.12. 4 Comparing perceptions of access to proper equipment within each design phase

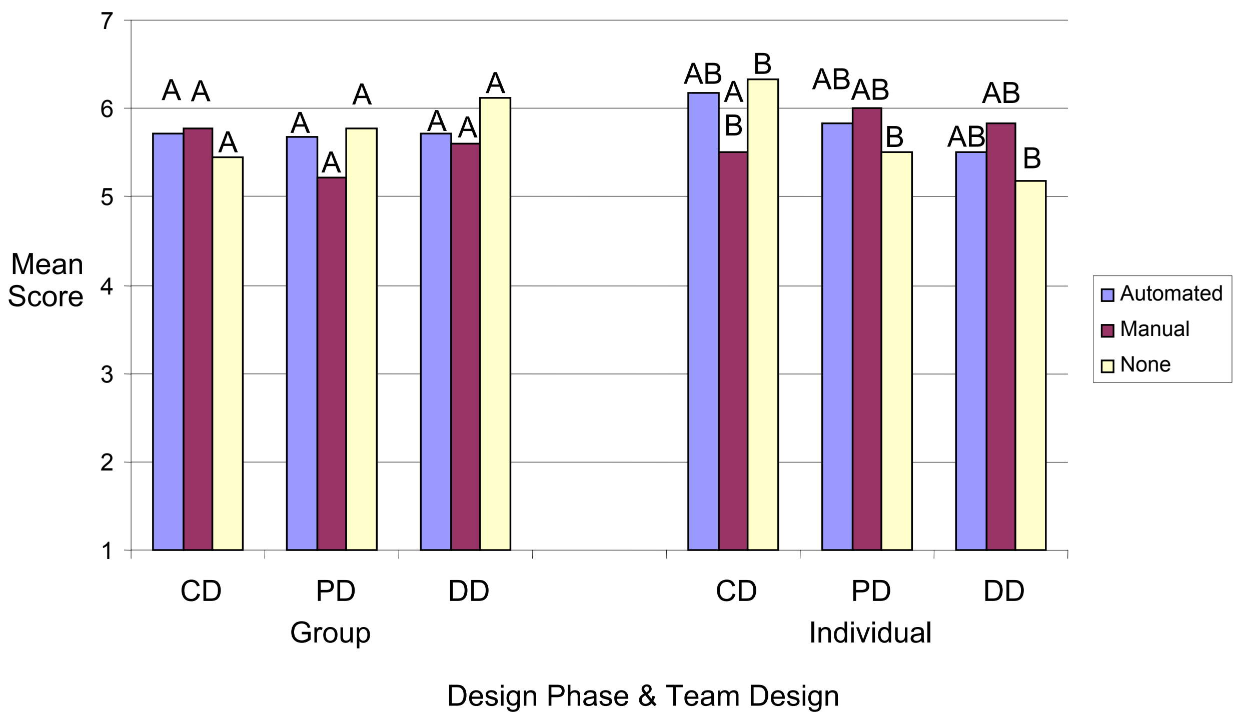


Figure A.12. 5 Comparing perceptions of access to proper equipment within each type of team design

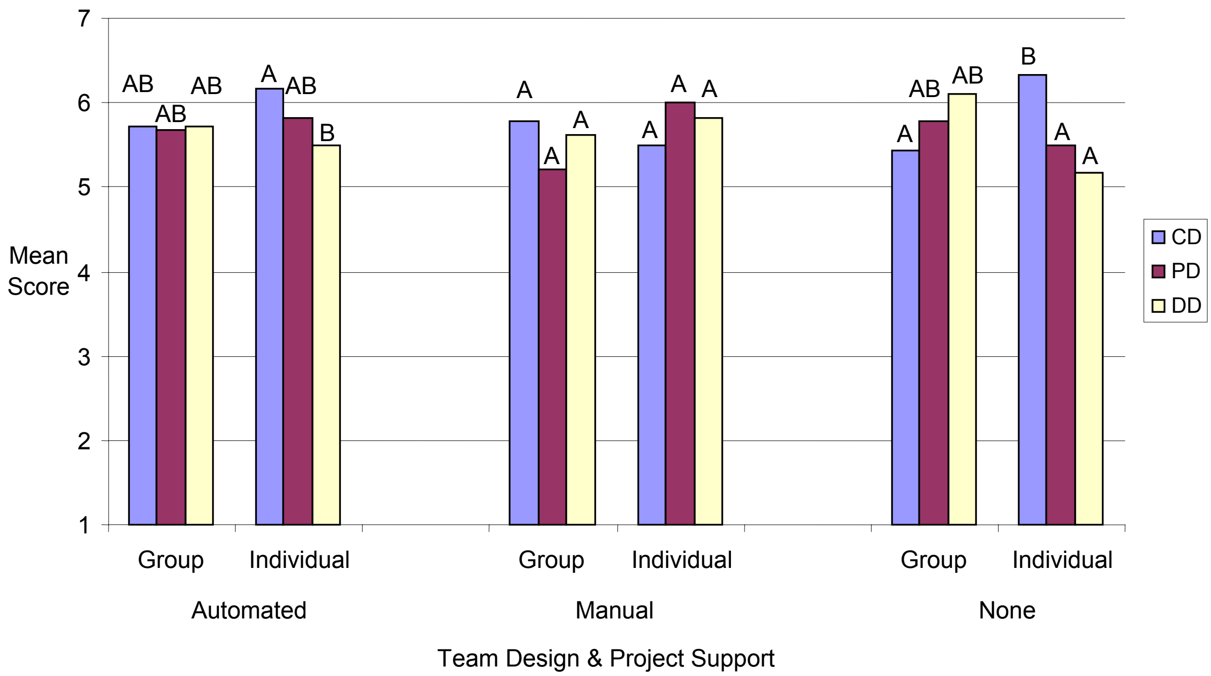


Figure A.12. 6 Comparing perceptions of access to proper equipment within each level of project support

Appendix A.13 ANOVA tables for variables that did not have significant effects

This appendix contains the analysis of variance tables for variables in which no significant effects were found in the analysis that included roles from Chapter 6.

A.13.1 NASA TLX

Planning

Table A. 13.1 ANOVA for NASA TLX during planning

Source	DF	SS	MS	F	P
PS	1	19.75	19.75	1.84	0.185
R	2	33.58	16.79	1.57	0.225
PS*R	2	4.06	2.03	0.19	0.828
s/PS*R	30	321.33	10.71		
Total	35	378.72			

Table A. 13.2 ANOVA for mental demand during planning

Source	DF	SS	MS	F	P
PS	1	15.01	15.01	0.60	0.443
R	2	100.78	50.39	2.03	0.149
PS*R	2	12.03	6.02	0.24	0.786
s/PS*R	30	744.98	24.83		
Total	35	872.80			

Table A. 13.3 ANOVA for physical demand during planning (transformed: Log(x+1))

Source	DF	SS	MS	F	P
PS	1	0.1123	0.1123	1.55	0.223
R	2	0.0527	0.0264	0.36	0.698
PS*R	2	0.2400	0.1200	1.66	0.208
s/PS*R	30	2.1742	0.0725		
Total	35	2.5792			

Table A. 13.4 ANOVA for performance during planning

Source	DF	SS	MS	F	P
PS	1	0.49	0.49	0.03	0.870
R	2	8.88	4.44	0.25	0.784
PS*R	2	4.99	2.49	0.14	0.872
s/PS*R	30	543.04	18.10		
Total	35	557.40			

Table A. 13.5 ANOVA for frustration during planning

Source	DF	SS	MS	F	P
PS	1	21.89	21.89	0.63	0.432
R	2	20.33	10.16	0.29	0.747
PS*R	2	7.85	3.92	0.11	0.893
s/PS*R	30	1034.31	34.48		
Total	35	1084.38			

Reflective

Table A. 13.6 ANOVA for the reflective NASA TLX

Source	DF	SS	MS	F	P
PS	2	1.114	0.557	0.16	0.855
Role	2	3.496	1.748	0.49	0.614
pm*role	4	26.811	6.703	1.89	0.129
s/pm*role	45	159.741	3.550		
Total	53	191.162			

Table A. 13.7 ANOVA for the reflective mental demand

Source	Effect	DF	Variance component	F value	Probability
PS	Fixed	2		0.73	0.4875
R	Fixed	2		1.58	0.2254
PS*R	Fixed	4		1.86	0.1442
Residual D	Random	15	22.6282		
Residual M	Random	15	6.3146		
Residual P	Random	15	20.9250		

Table A. 13.8 ANOVA for the reflective temporal demand (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.1296	0.0648	0.60	0.554
R	2	0.2078	0.0139	0.13	0.880
PS*R	4	0.7702	0.1926	1.78	0.149
s/PS*R	45	4.8662	0.1081		
Total	53	5.7938			

Table A. 13.9 ANOVA for the reflective performance

Source	DF	SS	MS	F	P
PS	2	3.02	1.51	0.09	0.910
R	2	89.11	44.55	2.79	0.072
PS*R	4	16.47	4.12	0.26	0.903
s/PS*R	45	719.40	15.99		
Total	53	828.01			

Table A. 13.10 ANOVA for the reflective effort

Source	DF	SS	MS	F	P
PS	2	14.35	7.18	0.55	0.582
R	2	24.48	12.24	0.93	0.401
PS*R	4	44.38	11.09	0.85	0.503
s/PS*R	45	589.89	13.11		
Total	53	673.09			

Table A. 13.11 ANOVA for the reflective frustration

Source	DF	SS	MS	F	P
PS	2	50.70	25.35	0.68	0.513
R	2	13.80	6.90	0.18	0.832
PS*R	4	38.18	9.55	0.26	0.905
s/PS*R	45	1682.23	37.38		
Total	53	1784.91			

A.13.2 Job Satisfaction

Planning

Table A. 13.12 ANOVA for job satisfaction during planning (with group data)

Source	DF	SS	MS	F	P
PS	1	173.36	173.36	2.45	0.128
R	2	15.06	7.53	0.11	0.899
PS*R	2	173.39	86.69	1.23	0.307
S/PS*R	30	2119.17	70.64		
Total	35	2480.97			

Table A. 13.13 ANOVA for comfort during planning

Source	DF	SS	MS	F	P
PS	1	20.25	20.25	1.93	0.175
R	2	5.17	2.58	0.25	0.784
PS*R	2	32.17	16.08	1.53	0.233
S/PS*R	30	315.17	10.51		
Total	35	372.75			

Table A. 13.14 ANOVA for the perception that excessive work was required during planning

Source	DF	SS	MS	F	P
PS	1	2.250	2.250	1.92	0.176
R	2	0.667	0.333	0.28	0.755
PS*R	2	0.667	0.333	0.28	0.755
s/PS*R	30	35.167	1.172		
Total	35	38.750			

Table A. 13.15 ANOVA for the physical surroundings was required during planning

Source	DF	SS	MS	F	P
PS	1	1.000	1.000	1.00	0.325
R	2	0.056	0.028	0.03	0.973
PS*R	2	1.500	0.750	0.75	0.481
s/PS*R	30	30.000	1.000		
Total	35	32.556			

Table A. 13.16 ANOVA for personal problems during planning

Source	DF	SS	MS	F	P
PS	1	3.361	3.361	1.69	0.203
R	2	3.389	1.694	0.85	0.436
PS*R	2	8.722	4.361	2.20	0.128
s/PS*R	30	59.500	1.983		
Total	35	74.972			

Table A. 13.17 ANOVA for the develop ability during planning

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	1		1.70	0.2066
R	Fixed	2		1.04	0.3721
PS*R	Fixed	2		0.22	0.8035
Residual A	Random	21	0.5333		
Residual M	Random	21	2.7333		

Table A. 13.18 ANOVA for the perception the work was interesting during planning

Source	DF	SS	MS	F	P
PS	1	3.361	3.361	1.22	0.278
R	2	4.222	2.111	0.77	0.473
PS*R	2	3.556	1.778	0.65	0.531
s/PS*R	30	82.500	2.750		
Total	35	93.639			

Table A. 13.19 ANOVA for freedom during planning

Source	DF	SS	MS	F	P
PS	1	2.778	2.778	1.47	0.235
R	2	0.889	0.444	0.24	0.792
PS*R	2	9.556	4.778	2.53	0.097
s/PS*R	30	56.667	1.889		
Total	35	69.889			

Table A. 13.20 ANOVA for problem difficulty during planning

Source	DF	SS	MS	F	P
PS	1	0.694	0.694	0.59	0.448
R	2	2.889	1.444	1.23	0.306
PS*R	2	6.222	3.111	2.65	0.087
s/PS*R	30	35.167	1.172		
Total	35	44.972			

Table A. 13.21 ANOVA for ability to see work results during planning

Source	DF	SS	MS	F	P
PS	1	0.250	0.250	0.11	0.739
R	2	2.056	1.028	0.46	0.633
PS*R	2	2.167	1.083	0.49	0.618
s/PS*R	30	66.500	2.217		
Total	35	70.972			

Table A. 13.22 ANOVA for resources during planning

Source	DF	SS	MS	F	P
PS	1	4.694	4.694	0.50	0.483
R	2	2.722	1.361	0.15	0.865
PS*R	2	7.389	3.694	0.40	0.676
S/PS*R	30	279.500	9.317		
Total	35	294.306			

Table A. 13.23 ANOVA for appropriate equipment was available during planning

Source	DF	SS	MS	F	P
PS	1	3.361	3.361	3.07	0.090
R	2	0.056	0.028	0.03	0.975
PS*R	2	0.056	0.028	0.03	0.975
s/PS*R	30	32.833	1.094		
Total	35	36.306			

Table A. 13.24 ANOVA for information during planning

Source	DF	SS	MS	F	P
PS	1	0.0278	0.0278	0.03	0.856
R	2	1.0556	0.5278	0.56	0.580
PS*R	2	0.7222	0.3611	0.38	0.687
s/PS*R	30	28.5000	0.9500		
Total	35	30.3056			

Table A. 13.25 ANOVA for responsibility during planning

Source	DF	SS	MS	F	P
PS	1	0.000	0.000	0.000	1.000
R	2	1.556	0.778	0.63	0.539
PS*R	2	0.667	0.333	0.27	0.765
s/PS*R	30	37.000	1.233		
Total	35	39.222			

Table A. 13.26 ANOVA for member competence during planning

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	1		0.25	0.6211
R	Fixed	2		0.20	0.8238
PS*R	Fixed	2		0.59	0.5648
Residual G	Random	22	0.3778		
Residual I	Random	22	1.6111		

Table A. 13.27 ANOVA for member helpfulness during planning

Source	DF	SS	MS	F	P
PS	1	0.1111	0.1111	0.12	0.731
R	2	0.8889	0.4444	0.48	0.622
PS*R	2	1.5556	0.7778	0.84	0.440
s/PS*R	30	27.6667	0.922		
Total	35	30.2222			

Design Process

Table A. 13.28 Variance analysis for personal problems during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.53	0.5922
R	Fixed	2		1.53	0.2270
PS*R	Fixed	4		0.37	0.8310
s/PS*R	Random	46	1.1897		
Within					
DP	Fixed	2		2.15	0.1265
DP*PS	Fixed	4		0.84	0.5085
DP*R	Fixed	4		1.09	0.3716
DP*PS*R	Fixed	8		0.57	0.7982
Residual D	Random	31	0.1612		
Residual M	Random	29	0.1863		
Residual P	Random	31	1.0036		

Table A.13.29 Variance analysis for challenge during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		2.35	0.1072
R	Fixed	2		0.44	0.6451
PS*R	Fixed	4		2.31	0.0727
s/PS*R	Random	43	6.5553		
Within					
DP	Fixed	2		2.05	0.1400
DP*PS	Fixed	2		0.22	0.9280
DP*R	Fixed	4		0.08	0.9883
DP*PS*R	Fixed	4		0.54	0.8217
Residual CD	Random		6.7792		
Residual PD	Random		5.4755		
Residual DD	Random		13.5883		

Table A.13.30 Variance analysis for freedom during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		1.01	0.3719
R	Fixed	2		1.21	0.3086
PS*R	Fixed	4		0.74	0.5679
s/PS*R	Random	48	0.9018		
Within					
DP	Fixed	2		1.50	0.2331
DP*PS	Fixed	2		0.40	0.8067
DP*R	Fixed	4		0.46	0.7669
DP*PS*R	Fixed	4		0.84	0.5668
Residual CD	Random	12	0.3964		
Residual PD	Random	27	0.8717		
Residual DD	Random	33	1.4185		

Table A.13.31 Variance analysis for problem difficulty during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.39	0.6827
R	Fixed	2		1.17	0.3179
PS*R	Fixed	4		1.97	0.1155
s/PS*R	Random	16	0.3896		
Within					
DP	Fixed	2		2.46	0.0918
DP*PS	Fixed	2		0.62	0.6467
DP*R	Fixed	4		0.22	0.9255
DP*PS*R	Fixed	4		0.75	0.6459
Residual CD	Random	33	0.4313		
Residual PD	Random	36	1.4376		
Residual DD	Random	26	0.6352		

Table A. 13.32 Variance analysis on equipment during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.47	0.6268
R	Fixed	2		1.80	0.1766
PS*R	Fixed	4		2.51	0.0549
s/PS*R	Random	45	0.2852		
Within					
DP	Fixed	2		1.05	0.3526
DP*PS	Fixed	4		1.44	0.2267
DP*R	Fixed	4		0.76	0.5533
DP*PS*R	Fixed	8		1.24	0.2837
DP*s/PS*R	Random	90	0.8840		

Table A. 13.33 Variance analysis for information during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		2.80	0.0713
R	Fixed	2		1.16	0.3232
PS*R	Fixed	4		1.19	0.3308
s/PS*R	Random	11	0.3017		
Within					
DP	Fixed	2		2.05	0.1366
DP*PS	Fixed	4		1.16	0.3382
DP*R	Fixed	4		0.87	0.4905
DP*PS*R	Fixed	8		1.09	0.3867
Residual D	Random	32	0.2198		
Residual M	Random	34	1.1289		
Residual P	Random	25	1.0694		

Table A. 13.34 Variance analysis on responsibility during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		1.90	0.1609
R	Fixed	2		0.20	0.8180
PS*R	Fixed	4		0.77	0.5477
s/PS*R	Random	45	0.2037		
Within					
DP	Fixed	2		1.08	0.3446
DP*PS	Fixed	4		0.67	0.6149
DP*R	Fixed	4		0.81	0.5210
DP*PS*R	Fixed	8		1.02	0.4299
DP*s/PS*R	Random	90	0.5210		

Reflective

Table A. 13.35 ANOVA for reflective job satisfaction

Source	DF	SS	MS	F	P
PS	2	256.44	128.22	1.68	0.198
R	2	17.44	8.72	0.11	0.892
PS*R	4	343.11	85.78	1.12	0.358
S/PS*R	45	3438.33	76.41		
Total	53	4055.33			

Table A. 13.36 ANOVA for reflective comfort

Source	DF	SS	MS	F	P
PS	2	20.59	10.30	0.95	0.395
R	2	17.81	8.91	0.82	0.447
PS*R	4	8.07	2.02	0.19	0.945
S/PS*R	45	489.17	10.87		
Total	53	535.65			

Table A. 13.37 ANOVA for excessive work (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.1152	0.05761	1.60	0.213
R	2	0.0669	0.03344	0.93	0.402
PS*R	4	0.0270	0.00675	0.19	0.944
s/PS*R	45	1.6192	0.03598		
Total	53	1.8283			

Table A. 13.38 ANOVA for reflective physical surroundings

Source	DF	SS	MS	F	P
PS	2	4.3333	2.1667	2.47	0.096
R	2	0.3333	0.1667	0.19	0.828
PS*R	4	2.6667	0.6667	0.76	0.557
s/PS*R	45	39.5000	0.8778		
Total	53	46.8333			

Table A. 13.39 ANOVA for reflective time perception

Source	DF	SS	MS	F	P
PS	2	1.815	0.907	0.31	0.738
R	2	5.593	2.796	0.94	0.397
PS*R	4	9.185	2.296	0.77	0.548
s/PS*R	45	133.500	2.967		
Total	53	150.093			

Table A. 13.40 ANOVA for reflective personal problems

Source	DF	SS	MS	F	P
PS	2	2.259	1.130	0.95	0.394
R	2	2.259	1.130	0.95	0.394
PS*R	4	0.963	0.241	0.20	0.936
s/PS*R	45	53.500	1.189		
Total	53	58.981			

Table A. 13.41 ANOVA for reflective challenge

Source	DF	SS	MS	F	P
PS	2	42.93	21.46	1.75	0.185
R	2	1.81	0.91	0.07	0.929
PS*R	4	96.19	24.05	1.97	0.116
S/PS*R	45	550.33	12.23		
Total	53	691.26			

Table A. 13.42 ANOVA for reflective freedom

Source	DF	SS	MS	F	P
PS	2	3.593	1.796	1.23	0.302
R	2	3.370	1.685	1.15	0.324
PS*R	4	6.185	1.546	1.06	0.388
S/PS*R	45	65.667	1.459		
Total	53	78.815			

Table A. 13.43 ANOVA for reflective ability to see results (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.01063	0.00531	0.31	0.737
R	2	0.00393	0.00197	0.11	0.893
PS*R	4	0.08491	0.02123	1.23	0.312
S/PS*R	45	0.77756	0.01728		
Total	53	0.87704			

Table A. 13.44 ANOVA for reflective resources

Source	DF	SS	MS	F	P
PS	2	26.78	13.39	1.30	0.283
R	2	1.44	0.72	0.07	0.932
PS*R	4	67.11	16.78	1.63	0.183
S/PS*R	45	463.50	10.30		
Total	53	558.83			

Table A. 13.45 ANOVA for the reflective appropriate equipment availability

Source	DF	SS	MS	F	P
PS	2	3.0000	1.5000	1.78	0.180
R	2	0.7778	0.3889	0.46	0.633
PS*R	4	1.2222	0.3056	0.36	0.833
s/PS*R	45	37.8333	0.8407		
Total	53	42.8333			

Table A. 13.46 ANOVA for the reflective information

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	2		1.51	0.2364
R	Fixed	2		1.16	0.3285
PS*R	Fixed	4		1.54	0.2164
Residual D	Random	15	0.4444		
Residual M	Random	15	0.5111		
Residual P	Random	15	1.8000		

Table A. 13.47 ANOVA for the reflective responsibility

Source	DF	SS	MS	F	P
PS	2	0.0370	0.0185	0.03	0.969
R	2	0.1481	0.0741	0.13	0.883
PS*R	4	3.2963	0.8241	1.39	0.252
s/PS*R	45	26.6667	0.5926		
Total	53	30.1481			

Table A. 13.48 ANOVA for reflective member competency (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.03203	0.01601	1.34	0.273
R	2	0.00087	0.00043	0.04	0.964
PS*R	4	0.09744	0.02436	2.03	0.106
S/PS*R	45	0.53948	0.01199		
Total	53	0.66982			

Table A. 13.49 ANOVA for the reflective member helpfulness

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	2		0.30	0.7444
R	Fixed	2		0.37	0.6930
PS*R	Fixed	4		1.60	0.2016
Residual D	Random	15	0.5000		
Residual M	Random	15	0.2778		
Residual P	Random	15	1.6444		

A.13.3 Supplemental Design Questions

Reflective

Table A. 13.50 ANOVA for the participants' belief that they build the best system possible

Source	DF	SS	MS	F	P
PS	2	17.444	8.772	2.49	0.094
R	2	2.778	1.389	0.40	0.674
PS*R	4	1.111	0.278	0.08	0.988
s/PS*R	45	157.500	3.500		
Total	53	178.833			

Table A. 13.51 ANOVA for the degree to which the participants liked their system (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.0063	0.0032	0.04	0.957
R	2	0.1580	0.0790	1.09	0.344
PS*R	4	0.1006	0.0252	0.35	0.844
s/PS*R	45	3.2565	0.0724		
Total	53	3.5215			

Table A. 13.52 ANOVA for the participants' belief that they met or exceeded their design objectives

Source	DF	SS	MS	F	P
PS	2	6.259	3.130	0.66	0.522
R	2	8.037	4.019	0.85	0.435
PS*R	4	0.741	0.185	0.04	0.997
s/PS*R	45	213.333	4.741		
Total	53	228.370			

A.13.4 Supplemental Planning Questions

Planning

Table A. 13.53 ANOVA for the effectiveness of the project support tools during planning

Source	DF	SS	MS	F	P
PS	1	3.361	3.361	2.02	0.165
R	2	2.000	1.000	0.60	0.554
PS*R	2	1.556	0.778	0.47	0.631
s/PS*R	30	49.833	1.661		
Total	35	56.750			

Design Process

Table A. 13.54 ANOVA for efficiency of project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.51	0.4800
R	Fixed	2		0.51	0.6047
PS*R	Fixed	4		1.39	0.2651
s/PS*R	Random	30	0.9037		
Within					
DP	Fixed	2		0.58	0.5657
DP*PS	Fixed	2		0.04	0.9567
DP*R	Fixed	4		1.09	0.3699
DP*PS*R	Fixed	4		0.53	0.7174
Residual	Random	60	0.8370		

Table A. 13.55 ANOVA for productivity of project support tools during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		2.27	0.1423
R	Fixed	2		1.10	0.3302
PS*R	Fixed	4		1.41	0.2597
s/PS*R	Random	30	0.2937		
Within					
DP	Fixed	2		0.93	0.4019
DP*PS	Fixed	2		0.17	0.8443
DP*R	Fixed	4		1.76	0.1498
DP*PS*R	Fixed	4		0.44	0.7786
Residual	Random	60	0.3087		

Reflective

Table A. 13.56 ANOVA for how well project support tools enabled participants to stay on schedule

Source	DF	SS	MS	F	P
PS	1	0.028	0.028	0.01	0.904
R	2	6.889	3.444	1.83	0.178
PS*R	2	0.889	0.444	0.24	0.791
s/PS*R	30	56.500	1.883		
Total	35	64.306			

Table A. 13.57 ANOVA for how well project support tools enabled the participants to stay on budget

Source	DF	SS	MS	F	P
PS	1	0.250	0.250	0.14	0.716
R	2	6.722	3.361	1.82	0.180
PS*R	2	1.167	0.583	0.32	0.732
s/PS*R	30	55.500	1.850		
Total	35	63.639			

A.13.5 Group Workload

Planning

Table A. 13.58 ANOVA for the value of group interaction during planning

Source	DF	SS	MS	F	P
PS	1	13.15	13.15	1.10	0.303
R	2	6.97	3.49	0.29	0.750
PS*R	2	12.21	6.11	0.51	0.606
s/PS*R	30	359.76	11.99		
Total	35	392.09			

Table A. 13.59 ANOVA for the difficulty of group interaction during planning

Source	DF	SS	MS	F	P
PS	1	12.83	12.83	0.40	0.532
R	2	15.78	7.89	0.25	0.783
PS*R	2	22.41	11.21	0.35	0.708
s/PS*R	30	961.97	32.07		
Total	35	1013.00			

Table A. 13.60 ANOVA for the degree of cooperation during planning

Source	DF	SS	MS	F	P
PS	1	8.21	8.21	0.60	0.443
R	2	38.84	19.42	1.43	0.255
PS*R	2	6.87	3.43	0.25	0.778
s/PS*R	30	407.65	13.59		
Total	35	461.57			

Table A. 13.61 ANOVA for the overall team workload during planning

Source	DF	SS	MS	F	P
PS	1	24.71	24.71	1.18	0.285
R	2	25.50	12.75	0.61	0.550
PS*R	2	2.40	1.20	0.06	0.944
s/PS*R	30	626.25	20.88		
Total	35	678.86			

Reflective

Table A. 13.62 ANOVA for the reflective value of group interaction (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.3362	0.1681	1.82	0.173
R	2	0.0115	0.0058	0.06	0.939
PS*R	4	0.3509	0.0877	0.95	0.443
s/PS*R	45	4.1490	0.0922		
Total	53	4.8456			

Table A. 13.63 ANOVA for the reflective difficulty of group interaction

Source	DF	SS	MS	F	P
PS	2	46.73	23.37	0.84	0.439
R	2	104.76	52.38	1.88	0.164
PS*R	4	23.31	5.83	0.21	0.932
s/PS*R	45	1253.26	27.85		
Total	53	1438.06			

Table A. 13.64 ANOVA for the reflective degree of cooperation (transformed: Log_{10}(reflected x+1))

Source	DF	SS	MS	F	P
PS	2	0.02057	0.01028	0.11	0.893
R	2	0.16506	0.08253	0.91	0.410
PS*R	4	0.30266	0.07567	0.83	0.510
s/PS*R	45	4.08044	0.09068		
Total	53	4.56873			

A.13.6 Group Workload Evaluated by Outside Observers

Planning

Table A. 13.65 ANOVA for value of group interaction during planning evaluated by outside observers

Source	DF	SS	MS	F	P
PS	1	1.172	1.172	0.28	0.610
S/PS	10	42.381	4.238		
Total	11	43.553			

Table A. 13.66 ANOVA for the degree of group interaction during planning evaluated by outside observers

Source	DF	SS	MS	F	P
PS	1	0.064	0.064	0.01	0.925
S/PS	10	68.715	6.871		
Total	11	68.779			

Table A. 13.67 ANOVA for the degree of cooperation during planning evaluated by outside observers

Source	DF	SS	MS	F	P
PS	1	1.603	1.603	0.34	0.574
S/PS	10	47.427	4.743		
Total	11	49.030			

Table A. 13.68 ANOVA for the overall team workload during planning evaluated by outside observers

Source	DF	SS	MS	F	P
PS	1	12.26	12.26	0.88	0.371
S/PS	10	139.41	13.94		
Total	11	151.66			

Design Process

Table A. 13.69 ANOVA for the value of group evaluated by outside observers

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.84	0.4527
S/PS	Random	15	2.5227		
Within					
DP	Fixed	2		1.84	0.1757
PS*DP	Fixed	4		1.12	0.3647
S*DP/PS	Random	30	1.6131		

Table A. 13.70 ANOVA for the degree of cooperation evaluated by outside observers

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.31	0.7414
S/PS	Random	15	1.4897		
Within					
DP	Fixed	2		0.77	0.4738
PS*DP	Fixed	4		1.62	0.1941
S*DP/PS	Random	30	2.5224		

Reflective

Table A. 13.71 ANOVA for the reflective value of group interaction evaluated by outside observers

Source	DF	SS	MS	F	P
PS	2	1.703	0.852	0.13	0.875
S/PS	15	95.021	6.335		
Total	17	96.724			

Table A. 13.72 ANOVA for the reflective difficulty of group interaction evaluated by outside observers

Source	DF	SS	MS	F	P
PS	2	8.370	4.185	0.91	0.424
S/PS	15	69.115	4.608		
Total	17	77.485			

Table A. 13.73 ANOVA for the reflective degree of cooperation evaluated by outside observers

Source	DF	SS	MS	F	P
PS	2	0.606	0.303	0.10	0.906
S/PS	15	45.915	3.061		
Total	17	46.522			

Table A. 13.74 ANOVA for the reflective overall team workload evaluated by outside observers

Source	DF	SS	MS	F	P
PS	2	8.105	4.053	1.26	0.313
S/PS	15	48.376	3.225		
Total	17	56.481			

A.13.7 Critical Team Behaviors

Planning

Table A. 13.75 Logistic analysis for negative communication during planning

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	1		1.00	0.3258
R	Fixed	2		0.38	0.6879
PS*R	Fixed	2		0.20	0.8228
s/PS*R	Random	30	0.8033		

Table A. 13.76 ANOVA for negative cooperation during planning (transformed: $\sqrt{(x+1)}+\sqrt{x}$)

Source	DF	SS	MS	F	P
PS	1	0.6784	0.6784	1.39	0.247
R	2	0.097	0.0048	0.01	0.990
PS*R	2	0.5692	0.2846	0.58	0.564
s/PS*R	30	14.6142	0.4871		

Total	35	15.8714			

Table A. 13.77 ANOVA for positive cooperation during planning

Source	DF	SS	MS	F	P
PS	1	8.028	8.028	2.24	0.145
R	2	0.389	0.194	0.05	0.947
PS*R	2	0.722	0.361	0.10	0.904
s/PS*R	30	107.417	3.581		
Total	35	116.556			

Table A. 13.78 Logistic analysis for positive acceptance of feedback during planning

Source	Effect	DF	Variance Component	F value	Probability
PS	Fixed	1		0.76	0.3901
R	Fixed	2		0.48	0.6208
PS*R	Fixed	2		0.12	0.8878
s/PS*R	Random	30	0.8033		

Table A. 13.79 ANOVA for the positive adaptability during planning (transformed: $\sqrt{(x+1)} + \sqrt{x}$)

Source	DF	SS	MS	F	P
PS	1	1.1338	1.338	3.08	0.089
R	2	0.3839	0.1919	0.52	0.599
PS*R	2	2.4124	1.2062	3.28	0.052
s/PS*R	30	11.0388	0.3680		
Total	35	14.9689			

Table A. 13.80 ANOVA for the positive team spirit and morale during planning

Source	DF	SS	MS	F	P
PS	1	0.4444	0.4444	0.85	0.365
R	2	0.5972	0.2986	0.57	0.572
PS*R	2	0.0972	0.0486	0.09	0.912
s/PS*R	30	15.7500	0.5250		
Total	35	16.8889			

<u>Over Time</u>

Table A. 13.81 Logistic analysis for the positive communication during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		1.02	0.3631
R	Fixed	2		0.07	0.9359
PS*R	Fixed	4		0.34	0.8472
s/PS*R	Random	132	5.3513		
Within					
DP	Fixed	2		0.50	0.6096
DP*PS	Fixed	4		1.27	0.2884
DP*R	Fixed	4		0.13	0.9715
DP*PS*R	Fixed	8		0.95	0.4827
DP*S/(PS*R)	Random	97	0.3400		

Table A. 13.82 Logistic analysis for the negative cooperation during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		2.09	0.1301
R	Fixed	2		0.91	0.4069
PS*R	Fixed	4		1.07	0.3787
s/PS*R	Random	79	4.9336		
Within					
DP	Fixed	2		0.30	0.5838
DP*PS	Fixed	4		0.62	0.5422
DP*R	Fixed	4		0.19	0.8300
DP*PS*R	Fixed	8		1.25	0.3017
DP*S/(PS*R)	Random	49	0.4626		

Table A. 13.83 Logistic analysis for the negative coordination during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.27	0.7612
R	Fixed	2		2.07	0.1308
PS*R	Fixed	4		0.22	0.9256
s/PS*R	Random		1.9281		
Within					
DP	Fixed	2		0.85	0.4325
DP*PS	Fixed	4		0.45	0.7697
DP*R	Fixed	4		0.45	0.7731
DP*PS*R	Fixed	8		0.83	0.5762
DP*S/(PS*R)	Random		0.6123		

Table A. 13.84 Logistic analysis for the positive accepting feedback during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		1.88	0.1590
R	Fixed	2		1.91	0.1537
PS*R	Fixed	4		0.34	0.8506
s/PS*R	Random		0.0000		
Within					
DP	Fixed	2		0.09	0.7610
DP*PS	Fixed	4		0.20	0.8178
DP*R	Fixed	4		0.09	0.9130
DP*PS*R	Fixed	8		0.34	0.8532
DP*S/(PS*R)	Random		0.8420		

Table A. 13.85 Variance analysis for the positive team spirit and morale during design

Source	Effect	DF	Variance Component	F value	Probability
Between					
PS	Fixed	2		0.01	0.9931
R	Fixed	2		0.13	0.8778
PS*R	Fixed	4		0.48	0.7491
s/PS*R	Random	1	0.00507		
Within					
DP	Fixed	2		0.75	0.4779
DP*PS	Fixed	4		1.70	0.1607
DP*R	Fixed	4		0.84	0.5070
DP*PS*R	Fixed	8		0.64	0.7428
Residual CD	Random	26	0.1234		
Residual PD	Random	43	0.3274		
Residual PD	Random	36	0.1766		

Appendix A.14 MANOVAS for Group Analysis

The tables included in this appendix are for the MANOVAS for variables that are related to understanding the group process. This includes looking at the data presented in Chapters 4 and 5 and isolated the groups and determining the differences based on the individual perceptions of people in the group. In addition, there were several observations used in an attempt to learn if there were differences in group functioning based on the role individuals played, the point in time in the process, and the level of project support.

A.14.1 NASA TLX

Planning

Table A. 14.1 MANOVA on components of NASA TLX during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.571	3.129	6	25	0.020*
Hotelling	0.751	3.129	6	25	0.020*
Pillai	0.429	3.129	6	25	0.020*
Role					
Wilks	0.732	0.705	12	50	0.739
Hotelling	0.341	0.681	12	48	0.761
Pillai	0.288	0.728	12	52	0.717
Project Support * Role					
Wilks	0.818	0.441	12	50	0.938
Hotelling	0.218	0.436	12	48	0.941
Pillai	0.186	0.446	12	52	0.936

*p<0.05

Design Process

Table A. 14.2 MANOVA on components of the NASA TLX

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.881	0.43	12	80	0.9449
Hotelling	0.132	0.43	12	59	0.9442
Pillai	0.121	0.44	12	82	0.9423
Role					
Wilks	0.878	0.45	12	80	0.9388
Hotelling	0.135	0.44	12	59	0.9393
Pillai	0.125	0.46	12	82	0.9347
Design Phase					
Wilks	0.284	12.40	12	170	<0.0001*
Hotelling	2.222	15.61	12	129	<0.0001*
Pillai	0.799	9.54	12	172	<0.0001*
Project Support * Role					
Wilks	0.730	0.55	24	141	0.9540
Hotelling	0.333	0.54	24	86	0.9558
Pillai	0.297	0.58	24	172	0.9439
Project Support * Design Phase					
Wilks	0.735	1.15	24	298	0.2912
Hotelling	0.327	1.14	24	192	0.2994
Pillai	0.291	1.15	24	352	0.2850
Role * Design Phase					
Wilks	0.826	0.70	24	298	0.8518
Hotelling	0.200	0.70	24	192	0.8499
Pillai	0.183	0.70	24	352	0.8472
Project Support * Role * Design Phase					
Wilks	0.609	0.93	48	422	0.6061
Hotelling	0.530	0.92	48	266	0.6179
Pillai	0.463	0.94	48	540	0.5877

*p<0.05

Reflective

Table A. 14.3 MANOVA on components of reflective NASA TLX

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.804	0.768	12	80	0.681
Hotelling	0.235	0.763	12	78	0.686
Pillai	0.203	0.772	12	82	0.678
Role					
Wilks	0.816	0.713	12	80	0.734
Hotelling	0.216	0.703	12	78	0.744
Pillai	0.192	0.72	12	82	0.724
Project Support * Role					
Wilks	0.652	0.764	24	141	0.776
Hotelling	0.485	0.778	24	154	0.760
Pillai	0.379	0.750	24	172	0.793

A.14.2 Job Satisfaction

Planning

Table A. 14.4 MANOVA on components of job satisfaction during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.907	0.960	3	28	0.425
Hotelling	0.103	0.960	3	28	0.425
Pillai	0.093	0.960	3	28	0.425
Role					
Wilks	0.978	0.104	6	56	0.996
Hotelling	0.022	0.100	6	54	0.996
Pillai	0.022	0.107	6	58	0.995
Project Support * Role					
Wilks	0.241	1.323	6	58	0.262
Hotelling	0.771	1.296	6	56	0.274
Pillai	0.282	1.268	6	54	0.288

Table A. 14.5 MANOVA on the questions used to calculate job satisfaction during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.507	2.044	10	21	0.081
Hotelling	0.973	2.044	10	21	0.081
Pillai	0.493	2.044	10	21	0.081
Role					
Wilks	0.346	1.471	20	42	0.144
Hotelling	1.440	1.440	20	40	0.160
Pillai	0.810	1.499	20	44	0.130
Project Support * Role					
Wilks	0.635	0.535	20	42	0.934
Hotelling	0.521	0.521	20	40	0.940
Pillai	0.399	0.548	20	44	0.927

Design Process

Table A. 14.6 MANOVA on components of job satisfaction

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.827	1.43	6	86	0.2141
Hotelling	0.207	1.47	6	56	0.2052
Pillai	0.174	1.40	6	88	0.2248
Role					
Wilks	0.955	0.33	6	86	0.9190
Hotelling	0.046	0.33	6	56	0.9192
Pillai	0.050	0.34	6	88	0.9155
Design Phase					
Wilks	0.762	4.28	6	176	0.0005*
Hotelling	0.304	4.44	6	116	0.0004*
Pillai	0.245	4.14	6	178	0.0006*
Project Support * Role					
Wilks	0.680	1.49	12	114	0.1384
Hotelling	0.438	1.54	12	71	0.1302
Pillai	0.341	1.44	12	135	0.1541
Project Support * Design Phase					
Wilks	0.918	0.64	12	233	0.8102
Hotelling	0.087	0.63	12	149	0.8114
Pillai	0.083	0.64	12	270	0.8040
Role * Design Phase					
Wilks	0.858	1.15	12	233	0.3173
Hotelling	0.160	1.16	12	150	0.3183
Pillai	0.146	1.15	12	270	0.3163
Project Support * Role * Design Phase					
Wilks	0.654	1.68	24	256	0.0275*
Hotelling	0.467	1.66	24	184	0.0286*
Pillai	0.386	1.66	24	270	0.0292*

*p<0.05

Table A. 14.7 MANOVA on questions used to calculate job satisfaction

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.356	1.72	26	66	0.0407*
Hotelling	1.380	1.71	26	54	0.0488*
Pillai	0.796	1.73	26	68	0.0375*
Role					
Wilks	0.447	1.26	26	66	0.2245
Hotelling	1.027	1.27	26	54	0.2249
Pillai	0.647	1.25	26	68	0.2290
Design Phase					
Wilks	0.343	4.24	26	156	<0.0001***
Hotelling	1.600	4.75	26	132	<0.0001***
Pillai	0.765	3.77	26	158	<0.0001***
Project Support * Role					
Wilks	0.243	1.10	52	130	0.3273
Hotelling	1.850	1.13	52	86	0.3051
Pillai	1.124	1.08	52	144	0.3512
Project Support * Design Phase					
Wilks	0.585	0.87	52	304	0.7264
Hotelling	0.587	0.87	52	220	0.7276
Pillai	0.492	0.87	52	324	0.7177
Role * Design Phase					
Wilks	0.568	0.92	52	304	0.6356
Hotelling	0.622	0.92	52	220	0.6351
Pillai	0.515	0.92	52	324	0.6319
Project Support * Role * Design Phase					
Wilks	0.239	1.22	104	548	0.0851
Hotelling	1.658	1.22	104	344	0.0971
Pillai	1.252	1.21	104	680	0.0865

*p<0.05
***p<0.001

Reflection

Table A. 14.8 MANOVA on components of reflective job satisfaction

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.906	0.728	6	86	0.628
Hotelling	0.102	0.717	6	84	0.637
Pillai	0.096	0.738	6	88	0.620
Role					
Wilks	0.889	0.868	6	86	0.522
Hotelling	0.124	0.871	6	84	0.520
Pillai	0.111	0.863	6	88	0.525
Project Support * Role					
Wilks	0.712	1.301	12	114	0.228
Hotelling	0.380	1.319	12	125	0.216
Pillai	0.305	1.274	12	135	0.241

*p<0.05

Table A. 14.9 MANOVA on reflective questions used to determine job satisfaction and supplemental design questions

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.368	1.106	34	58	0.361
Hotelling	1.299	1.070	34	56	0.403
Pillai	0.786	1.142	34	60	0.321
Role					
Wilks	0.509	0.685	34	58	0.882
Hotelling	0.823	0.677	34	56	0.887
Pillai	0.563	0.691	34	60	0.877
Project Support * Role					
Wilks	0.180	0.935	68	116	0.614
Hotelling	2.234	0.904	68	110	0.672
Pillai	1.355	0.964	68	128	0.560

A.14.3 Supplemental Planning Support Questions

Design Process

Table A. 14.10 MANOVA on supplemental planning questions

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.789	1.39	5	26	0.2593
Hotelling	0.268	1.39	5	26	0.2593
Pillai	0.211	1.39	5	26	0.2593
Role					
Wilks	0.665	1.18	10	52	0.3270
Hotelling	0.491	1.25	10	36	0.2956
Pillai	0.344	1.12	10	54	0.3637
Design Phase					
Wilks	0.755	1.69	10	112	0.0918
Hotelling	0.312	1.73	10	81	0.0879
Pillai	0.254	1.66	10	114	0.0994
Project Support * Role					
Wilks	0.794	0.64	10	52	0.7768
Hotelling	0.251	0.64	10	36	0.7711
Pillai	0.212	0.64	10	54	0.7725
Project Support * Design Phase					
Wilks	0.790	1.40	10	112	0.1883
Hotelling	0.261	1.45	10	81	0.1751
Pillai	0.214	1.37	10	114	0.2053
Role * Design Phase					
Wilks	0.668	1.21	20	187	0.2536
Hotelling	0.446	1.23	20	116	0.2467
Pillai	0.366	1.19	20	236	0.2644
Project Support * Role * Design Phase					
Wilks	0.796	0.66	20	187	0.8570
Hotelling	0.243	0.67	20	116	0.8510
Pillai	0.215	0.67	20	236	0.8531

<u>Reflection</u>

Table A. 14.11 MANOVA on responses to reflective supplemental planning questions

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.781	1.889	4	27	0.141
Hotelling	0.280	1.889	4	27	0.141
Pillai	0.219	1.889	4	27	0.141
Role					
Wilks	0.718	1.216	8	54	0.308
Hotelling	0.360	1.171	8	52	0.334
Pillai	0.305	1.160	8	56	0.283
Project Support * Role					
Wilks	0.773	0.927	8	54	0.502
Hotelling	0.280	0.909	8	52	0.516
Pillai	0.238	0.944	8	56	0.489

A.14.4 Group Workload

<u>Planning</u>

Table A. 14.12 MANOVA on group workload during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.933	0.485	4	27	0.747
Hotelling	0.072	0.485	4	27	0.747
Pillai	0.067	0.485	4	27	0.747
Role					
Wilks	0.697	1.337	8	54	0.245
Hotelling	0.418	1.358	8	52	0.237
Pillai	0.316	1.312	8	56	0.257
Project Support * Role					
Wilks	0.833	0.644	8	54	0.737
Hotelling	0.198	0.642	8	52	0.729
Pillai	0.169	0.645	8	56	0.739

Design Process

Table A. 14.13 MANOVA on group workload

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.934	0.37	8	84	0.9351
Hotelling	0.071	0.37	8	58	0.9334
Pillai	0.067	0.37	8	86	0.9336
Role					
Wilks	0.844	0.93	8	84	0.4947
Hotelling	0.178	0.92	8	58	0.5069
Pillai	0.163	0.95	8	86	0.4775
Design Phase					
Wilks	0.464	10.17	8	174	<0.0001***
Hotelling	1.032	11.15	8	122	<0.0001***
Pillai	0.593	9.26	8	176	<0.0001***
Project Support * Role					
Wilks	0.725	0.90	16	129	0.5752
Hotelling	0.349	0.89	16	78	0.5776
Pillai	0.299	0.91	16	180	0.5617
Project Support * Design Phase					
Wilks	0.812	1.17	16	266	0.2888
Hotelling	0.220	1.18	16	168	0.2860
Pillai	0.197	1.17	16	360	0.2930
Role * Design Phase					
Wilks	0.851	0.90	16	226	0.5641
Hotelling	0.171	0.92	16	168	0.5457
Pillai	0.153	0.89	16	360	0.5775
Project Support * Role * Design Phase					
Wilks	0.752	0.81	32	322	0.7606
Hotelling	0.300	0.80	32	217	0.7658
Pillai	0.271	0.82	32	360	0.7488

***p<0.001

Reflection

Table A. 14.14 MANOVA on reflective group workload

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.758	1.561	8	84	0.149
Hotelling	0.305	1.565	8	82	0.148
Pillai	0.253	1.555	8	86	0.151
Role					
Wilks	0.734	1.758	8	84	0.097
Hotelling	0.341	1.747	8	82	0.100
Pillai	0.282	1.768	8	86	0.095
Project Support * Role					
Wilks	0.705	0.976	16	129	0.486
Hotelling	0.385	0.975	16	162	0.486
Pillai	0.318	0.972	16	180	0.489

A.14.5 Group Workload Assessed by Outside Observers

Planning

Table A. 14.15 MANOVA on group workload assessed by outside observers during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.795	0.452	4	7	0.769
Hotelling	0.258	0.452	4	7	0.769
Pillai	0.205	0.452	4	7	0.769

Design Process

Table A. 14.16 MANOVA on group workload assessed by outside observers

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.622	0.80	8	24	0.6061
Hotelling	0.549	0.79	8	15	0.6184
Pillai	0.414	0.85	8	26	0.5700
Design Phase					
Wilks	0.112	13.41	8	54	<0.0001***
Hotelling	6.049	21.42	8	36	<0.0001***
Pillai	1.049	7.73	8	56	<0.0001***
Project Support * Design Phase					
Wilks	0.475	1.43	16	83	0.1461
Hotelling	0.897	1.46	16	48	0.1541
Pillai	0.627	1.39	16	120	0.1560

***p<0.001

Reflective

Table A. 14.17 MANOVA on reflective group workload assessed by outside observers

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.765	0.430	8	24	0.892
Hotelling	0.292	0.401	8	22	0.908
Pillai	0.247	0.457	8	26	0.875

A.14.6 Critical Team Behaviors

Planning

Table A. 14.18 MANOVA on the all ineffective and effective behaviors during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.594	9.920	2	29	0.001**
Hotelling	0.684	9.920	2	29	0.001**
Pillai	0.406	9.920	2	29	0.001**
Role					
Wilks	0.847	1.259	4	58	0.296
Hotelling	0.181	1.264	4	56	0.295
Pillai	0.154	1.251	4	60	0.299
Project Support * Role					
Wilks	0.828	1.438	4	58	0.233
Hotelling	0.200	1.400	4	56	0.246
Pillai	0.179	1.475	4	60	0.221

**p<0.01

Table A. 14.19 MANOVA on the critical team behaviors during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.227	4.725	13	18	0.001**
Hotelling	3.413	4.725	13	18	0.001**
Pillai	0.773	4.725	13	18	0.001**
Role					
Wilks	0.324	1.047	26	36	0.443
Hotelling	1.533	1.002	26	34	0.491
Pillai	0.854	1.089	26	38	0.398
Project Support * Role					
Wilks	0.360	0.924	26	36	0.577
Hotelling	1.338	0.875	26	34	0.634
Pillai	0.800	0.973	26	38	0.520

**p<0.01

Design Process

Table A. 14.20 MANOVA on all positive and negative behavior observations

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.991	0.10	4	88	0.9835
Hotelling	0.009	0.10	4	52	0.9835
Pillai	0.009	0.10	4	90	0.9829
Role					
Wilks	0.691	4.47	4	88	0.0025**
Hotelling	0.447	4.88	4	52	0.0021**
Pillai	0.310	4.13	4	90	0.0040**
Design Phase					
Wilks	0.606	12.68	4	178	<0.0001***
Hotelling	0.651	14.43	4	106	<0.0001***
Pillai	0.394	11.06	4	180	<0.0001***
Project Support * Role					
Wilks	0.797	1.32	8	88	0.2423
Hotelling	0.247	1.34	8	61	0.2424
Pillai	0.210	1.32	8	90	0.2431
Project Support * Design Phase					
Wilks	0.958	0.48	8	178	0.8677
Hotelling	0.043	0.48	8	125	0.8687
Pillai	0.042	0.49	8	180	0.8643
Role * Design Phase					
Wilks	0.892	1.31	8	178	0.2424
Hotelling	0.118	1.31	8	125	0.2465
Pillai	0.110	1.32	8	180	0.2385
Project Support * Role * Design Phase					
Wilks	0.811	1.23	16	178	0.2504
Hotelling	0.223	1.23	16	142	0.2508
Pillai	0.197	1.23	16	180	0.2508

**p<0.01
***p<0.001

Table A. 14.21 MANOVA on critical team behaviors

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.394	1.36	28	64	0.1577
Hotelling	1.289	1.44	28	52	0.1280
Pillai	0.704	1.28	28	66	0.2038
Role					
Wilks	0.309	1.82	28	64	0.0245*
Hotelling	1.899	2.12	28	52	0.0096**
Pillai	0.7934	1.55	28	66	0.0737
Design Phase					
Wilks	0.226	6.07	28	154	<0.0001***
Hotelling	2.511	6.83	28	132	<0.0001***
Pillai	0.980	5.35	28	156	<0.0001***
Project Support * Role					
Wilks	0.330	0.75	56	127	0.8901
Hotelling	1.327	0.73	56	84	0.8970
Pillai	0.942	0.77	56	140	0.8664
Project Support * Design Phase					
Wilks	0.369	1.57	56	302	0.0091**
Hotelling	1.194	1.61	56	221	0.0082**
Pillai	0.848	1.54	56	320	0.0123*
Role * Design Phase					
Wilks	0.469	1.16	56	302	0.2225
Hotelling	0.855	1.16	56	221	0.2319
Pillai	0.674	1.16	56	320	0.2190
Project Support * Role * Design Phase					
Wilks	0.279	0.98	112	552	0.5328
Hotelling	1.448	0.97	112	348	0.5550
Pillai	1.136	0.99	112	672	0.5063

*p<0.05
**p<0.01
***p<0.001

A.14.7 Supplemental Group Observations

Planning

Table A. 14.22 MANOVA on the supplemental group observations during planning

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.623	4.076	4	27	0.010*
Hotelling	0.604	4.076	4	27	0.010*
Pillai	0.377	4.076	4	27	0.010*
Role					
Wilks	0.669	1.504	8	54	0.178
Hotelling	0.491	1.595	8	52	0.149
Pillai	0.334	1.404	8	56	0.215
Project Support * Role					
Wilks	0.850	0.570	8	54	0.798
Hotelling	0.173	0.564	8	52	0.803
Pillai	0.152	0.575	8	56	0.794

*p<0.05

Design Process

Table A. 14.23 MANOVA on supplemental group observations

Source	Test Statistic	F	DF		P
Project Support					
Wilks	0.639	2.63	8	84	0.0127*
Hotelling	0.530	2.74	8	58	0.0122*
Pillai	0.382	2.54	8	86	0.0156*
Role					
Wilks	0.647	2.57	8	84	0.0152*
Hotelling	0.525	2.72	8	58	0.0129*
Pillai	0.367	2.41	8	86	0.0211*
Design Phase					
Wilks	0.466	10.10	8	174	<0.0001***
Hotelling	0.938	10.13	8	122	<0.0001***
Pillai	0.630	10.11	8	176	<0.0001***
Project Support * Role					
Wilks	0.649	1.23	16	129	0.2566
Hotelling	0.487	1.25	16	78	0.2511
Pillai	0.387	1.21	16	180	0.2669
Project Support * Design Phase					
Wilks	0.741	1.72	16	266	0.0437*
Hotelling	0.334	1.79	16	168	0.0356*
Pillai	0.271	1.63	16	360	0.0582
Role * Design Phase					
Wilks	0.858	0.86	16	226	0.6218
Hotelling	0.161	0.87	16	168	0.6095
Pillai	0.146	0.85	16	360	0.6280
Project Support * Role * Design Phase					
Wilks	0.626	1.36	32	322	0.0967
Hotelling	0.515	1.38	32	217	0.0939
Pillai	0.427	1.34	32	360	0.1051

*p<0.05
***p<0.001

Appendix A.15 Multiple comparisons for significant three way interactions for group data

Table A. 15.1 Multiple comparisons for the three way interaction for comfort

Role changes while design phase and project support remain constant

	mean	CD Automated Manufacture	CD Automated Purchase
	mean	23.33	19.67
CD Automated Design	23.67	0.333	4.000*
CD Automated Manufacture	23.33		3.667

	mean	CD Manual Manufacture	CD Manual Purchase
	mean	22.50	23.33
CD Manual Design	22.67	0.167	0.667
CD Manual Manufacture	22.50		0.833

	mean	CD None Manufacture	CD None Purchase
	mean	24.50	25.67
CD None Design	24.50	0.00	1.167
CD None Manufacture	24.50		1.167

	mean	PD Automated Manufacture	PD Automated Purchase
	mean	21.50	22.83
PD Automated Design	21.67	0.333	1.667
PD Automated Manufacture	21.50		1.333

	mean	PD Manual Manufacture	PD Manual Purchase
	mean	22.00	19.50
PD Manual Design	21.33	0.667	1.833
PD Manual Manufacture	22.00		2.500

	mean	PD None Manufacture	PD None Purchase
	mean	23.50	24.67
PD None Design	23.67	0.167	1.00
PD None Manufacture	23.50		1.167

	mean	DD Automated Manufacture	DD Automated Purchase
	mean	21.17	21.67
DD Automated Design	20.17	1.00	1.500
DD Automated Manufacture	21.17		0.500

	mean	DD Manual Manufacture	DD Manual Purchase
	mean	18.67	21.67
DD Manual Design	20.67	2.000	1.000
DD Manual Manufacture	18.67		3.000

	mean	DD None Manufacture	DD None Purchase
	mean	22.67	24.50
DD None Design	21.50	1.167	3.000
DD None Manufacture	22.67		1.833

Design phase changes while role and project support remain constant

	mean	Design Automated PD	Design Automated DD
	mean	21.17	20.17
Design Automated CD	23.67	2.500	3.500**
Design Automated PD	21.17		1.000

	mean	Design Manual PD	Design Manual DD
	mean	21.33	20.67
Design Manual CD	22.67	1.333	2.00
Design Manual PD	21.33		0.667

	mean	Design None PD	Design None DD
	mean	23.67	21.50
Design None CD	24.50	0.833	3.000*
Design None PD	23.67		2.167

	mean	Manufacture Automated PD	Manufacture Automated DD
	mean	21.50	21.17
Manufacture Automated CD	23.33	1.833	2.167
Manufacture Automated PD	21.50		0.333

	mean	Manufacture Manual PD	Manufacture Manual DD
	mean	22.00	18.67
Manufacture Manual CD	22.50	0.500	3.833**
Manufacture Manual PD	22.00		3.333*

	mean	Manufacture None PD	Manufacture None DD
	mean	23.50	22.67
Manufacture None CD	24.50	1.000	1.833
Manufacture None PD	23.50		0.833

	mean	Purchase Automated PD	Purchase Automated DD
	mean	22.83	21.67
Purchase Automated CD	19.67	3.167*	2.000
Purchase Automated PD	22.83		1.167

	mean	Purchase Manual PD	Purchase Manual DD
	mean	19.50	21.67
Purchase Manual CD	23.33	3.833**	1.667
Purchase Manual PD	19.50		2.167

	mean	Purchase None PD	Purchase None DD
	mean	24.67	24.50
Purchase None CD	25.67	1.000	1.167
Purchase None PD	24.67		0.167

Design phase changes while role and project support remain constant

	mean	CD Design Manual	CD Design None
	mean	22.67	24.50
CD Design Automate	23.67	1.00	0.833
CD Design Manual	22.67		1.833

	mean	CD Manufacture Manual	CD Manufacture None
	mean	22.50	24.50
CD Manufacture Automate	23.33	0.833	1.167
CD Manufacture Manual	22.50		2.000

	mean	CD Purchase Manual	CD Purchase None
	mean	23.33	25.67
CD Purchase Automate	19.67	3.667	6.000**
CD Purchase Manual	23.33		2.333

	mean	PD Design Manual	PD Design None
	mean	21.33	23.67
PD Design Automate	21.67	0.167	2.500
PD Design Manual	21.33		2.333

	mean	PD Manufacture Manual	PD Manufacture None
	mean	22.00	23.50
PD Manufacture Automate	21.50	0.500	2.000
PD Manufacture Manual	22.00		1.500

	mean	PD Purchase Manual	PD Purchase None
	mean	19.50	24.67
PD Purchase Automate	22.83	3.333	1.833
PD Purchase Manual	19.50		5.1667*

	mean	DD Design Manual	DD Design None
	mean	20.67	21.50
DD Design Automate	20.17	0.500	1.333
DD Design Manual	20.67		0.833

	mean	DD Manufacture Manual	DD Manufacture None
	mean	18.67	22.67
DD Manufacture Automate	21.17	2.500	1.500
DD Manufacture Manual	18.67		4.000*

	mean	DD Purchase Manual	DD Purchase None
	mean	21.67	24.50
DD Purchase Automate	21.67	0.000	2.833
DD Purchase Manual	21.67		2.833

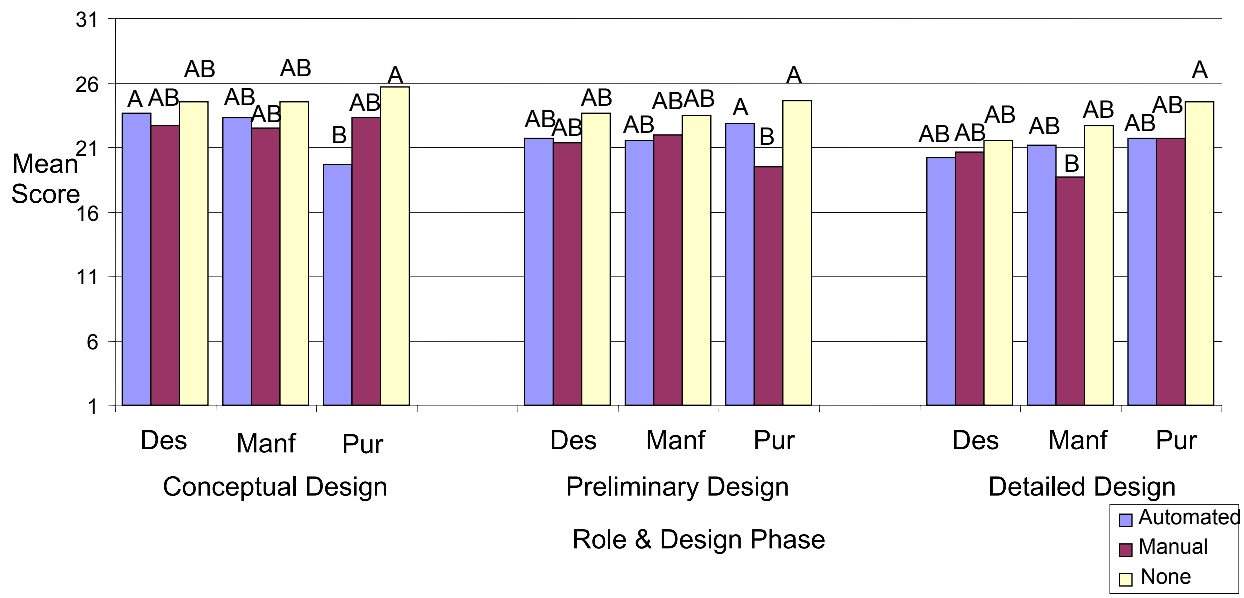


Figure A.15. 1 Comparing comfort for the three-way interaction within each design phase

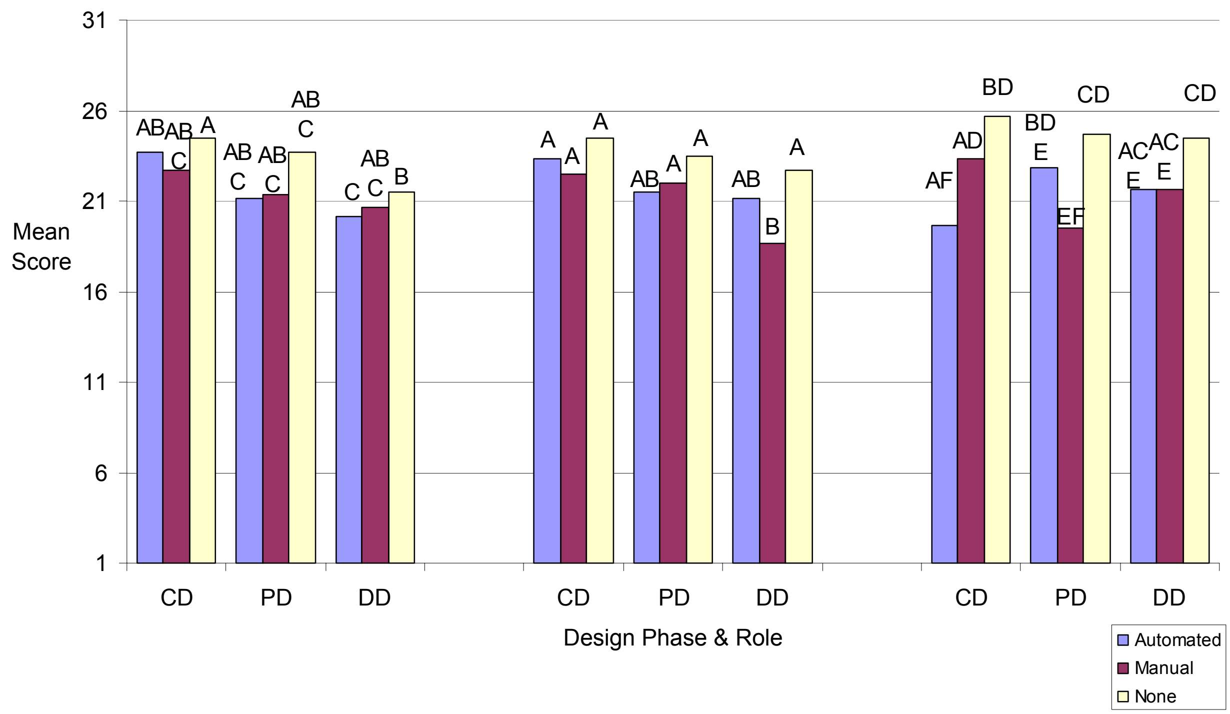


Figure A.15. 2 Comparing comfort for the three-way interaction within each role

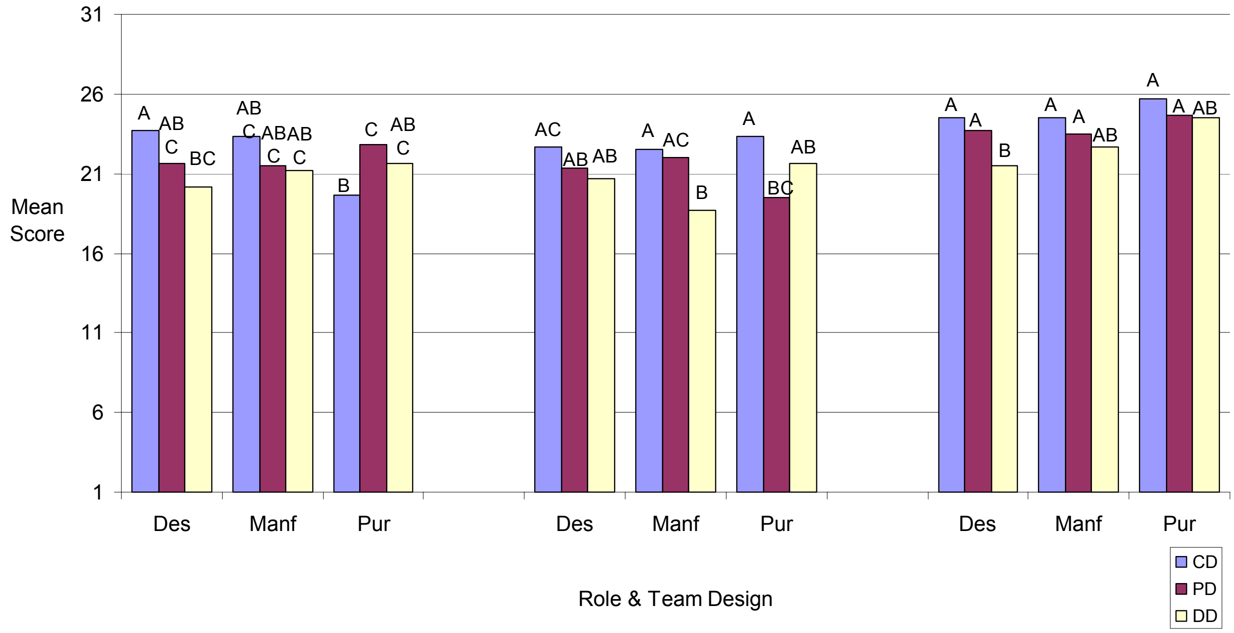


Figure A.15. 3 Comparing comfort for the three-way interaction within each project support level

Table A. 15.2 Multiple comparisons for the three way interaction for resources

Role changes while design phase and project support remain constant

	mean	CD Automated Manufacture	CD Automated Purchase
	mean	31.17	26.00
CD Automated Design	29.50	1.667	3.500
CD Automated Manufacture	31.17		5.167**

	mean	CD Manual Manufacture	CD Manual Purchase
	mean	29.17	29.83
CD Manual Design	29.33	0.167	0.500
CD Manual Manufacture	29.17		0.667

	mean	CD None Manufacture	CD None Purchase
	mean	28.67	32.5
CD None Design	30.00	1.333	2.500
CD None Manufacture	28.67		3.833

	mean	PD Automated Manufacture	PD Automated Purchase
	mean	29.17	26.67
PD Automated Design	29.67	0.500	3.000
PD Automated Manufacture	29.17		2.500

	mean	PD Manual Manufacture	PD Manual Purchase
	mean	28.67	29.00
PD Manual Design	26.50	2.167	2.500
PD Manual Manufacture	28.67		0.333

	mean	PD None Manufacture	PD None Purchase
	mean	29.67	31.67
PD None Design	30.17	0.667	1.500
PD None Manufacture	29.67		2.167

	mean	DD Automated Manufacture	DD Automated Purchase
	mean	27.33	25.67
DD Automated Design	30.33	3.000	4.667*
DD Automated Manufacture	27.33		1.667

	mean	DD Manual Manufacture	DD Manual Purchase
	mean	25.17	31.00
DD Manual Design	27.00	1.833	4.000*
DD Manual Manufacture	25.17		5.833**

	mean	DD None Manufacture	DD None Purchase
	mean	29.67	31.83
DD None Design	29.67	0.000	2.167
DD None Manufacture	29.67		2.167

Design phase changes while role and project support remain constant

	mean	Design Automated PD	Design Automated DD
	mean	29.67	30.33
Design Automated CD	29.5	0.167	0.833
Design Automated PD	29.67		0.667

	mean	Design Manual PD	Design Manual DD
	mean	26.50	27.00
Design Manual CD	29.33	2.833*	2.333
Design Manual PD	26.50		0.500

	mean	Design None PD	Design None DD
	mean	30.17	29.67
Design None CD	30.00	0.167	0.333
Design None PD	30.17		0.500

	mean	Manufacture Automated PD	Manufacture Automated DD
	mean	29.17	27.33
Manufacture Automated CD	31.17	2.00	3.833**
Manufacture Automated PD	29.17		1.833

	mean	Manufacture Manual PD	Manufacture Manual DD
	mean	28.67	25.17
Manufacture Manual CD	29.17	0.500	4.000**
Manufacture Manual PD	28.67		3.500**

	mean	Manufacture None PD	Manufacture None DD
	mean	29.50	29.67
Manufacture None CD	28.67	0.833	1.000
Manufacture None PD	29.50		0.167

	mean	Purchase Automated PD	Purchase Automated DD
	mean	26.67	25.67
Purchase Automated CD	26.00	0.667	0.333
Purchase Automated PD	26.67		1.000

	mean	Purchase Manual PD	Purchase Manual DD
	mean	29.00	31.00
Purchase Manual CD	29.83	0.833	1.667
Purchase Manual PD	29.00		2.000

	mean	Purchase None PD	Purchase None DD
	mean	31.67	31.83
Purchase None CD	32.50	0.833	0.667
Purchase None PD	31.67		0.167

Design phase changes while role and project support remain constant

		CD Design Manual	CD Design None
	mean		
	mean	29.33	30.00
CD Design Automate	29.50	0.167	0.500
CD Design Manual	29.33		0.667

		CD Manufacture Manual	CD Manufacture None
	mean		
	mean	29.17	28.67
CD Manufacture Automate	31.17	2.000	2.500
CD Manufacture Manual	29.17		0.500

		CD Purchase Manual	CD Purchase None
	mean		
	mean	29.83	32.50
CD Purchase Automate	26.00	3.883	6.500**
CD Purchase Manual	29.83		2.667

		PD Design Manual	PD Design None
	mean		
	mean	26.5	30.17
PD Design Automate	29.67	3.167	0.500
PD Design Manual	26.5		3.667

		PD Manufacture Manual	PD Manufacture None
	mean		
	mean	28.67	29.50
PD Manufacture Automate	29.17	0.500	0.333
PD Manufacture Manual	28.67		0.833

		PD Purchase Manual	PD Purchase None
	mean		
	mean	29.00	31.67
PD Purchase Automate	26.67	2.333	5.000*
PD Purchase Manual	29.00		2.667

		DD Design Manual	DD Design None
	mean		
	mean	27.00	29.67
DD Design Automate	30.33	3.333	0.667
DD Design Manual	27.00		2.667

		DD Manufacture Manual	DD Manufacture None
	mean		
	mean	25.17	29.67
DD Manufacture Automate	27.33	1.833	2.333
DD Manufacture Manual	25.17		4.500*

		DD Purchase Manual	DD Purchase None
	mean		
	mean	31.00	31.83
DD Purchase Automate	25.67	5.333**	6.167**
DD Purchase Manual	31.00		0.833

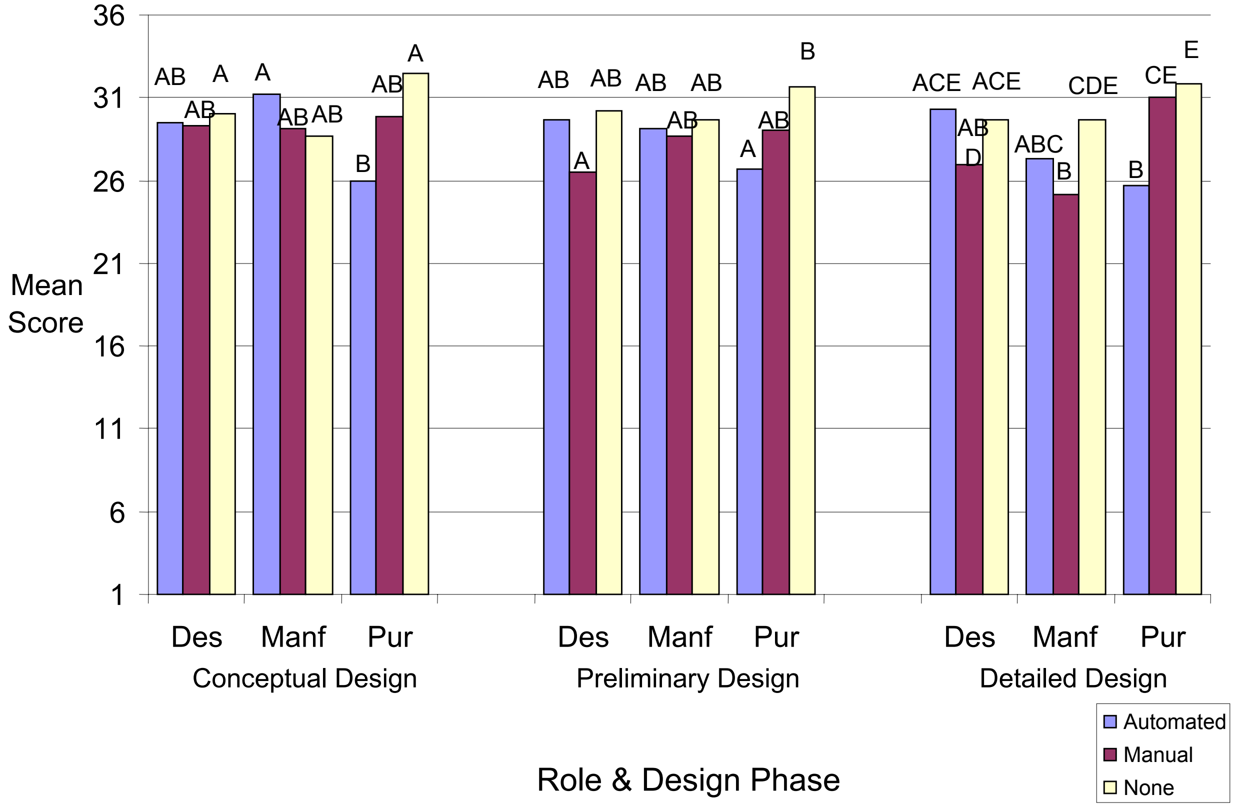


Figure A.15. 4 Comparisons of resources for the three-way interaction within each design phase

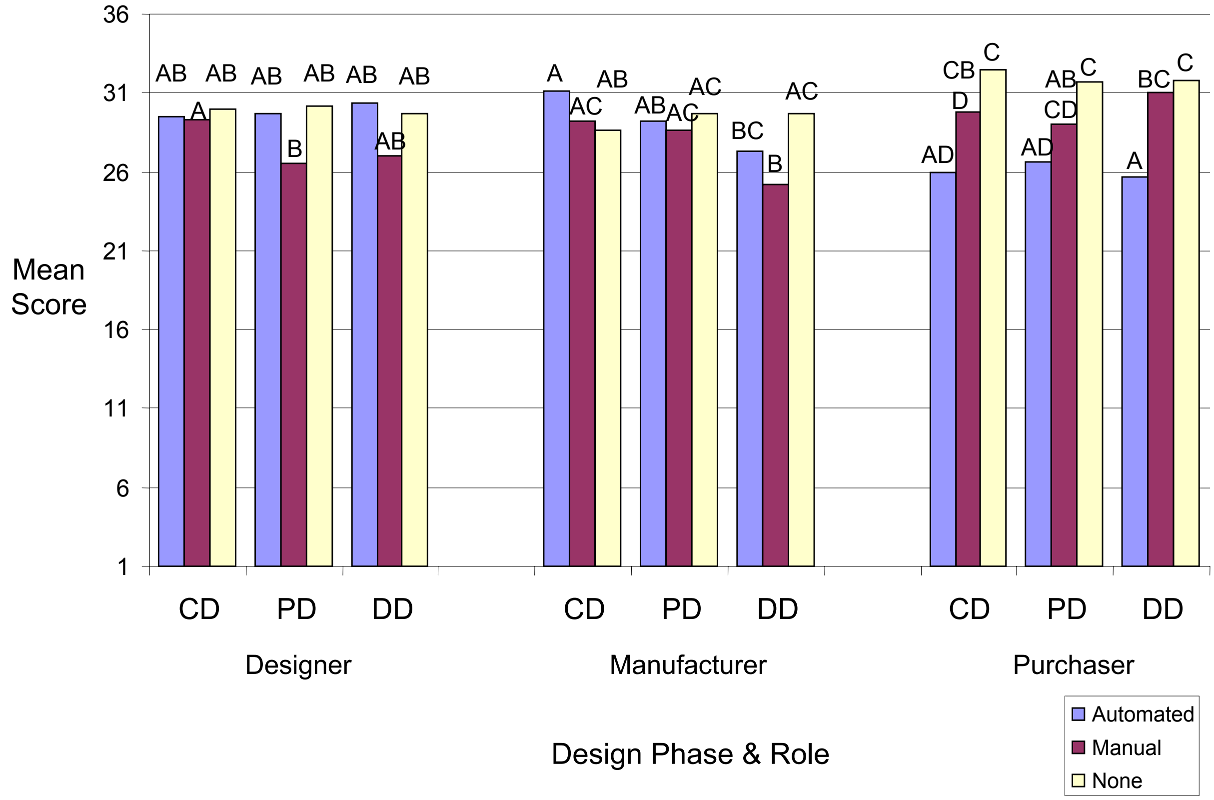
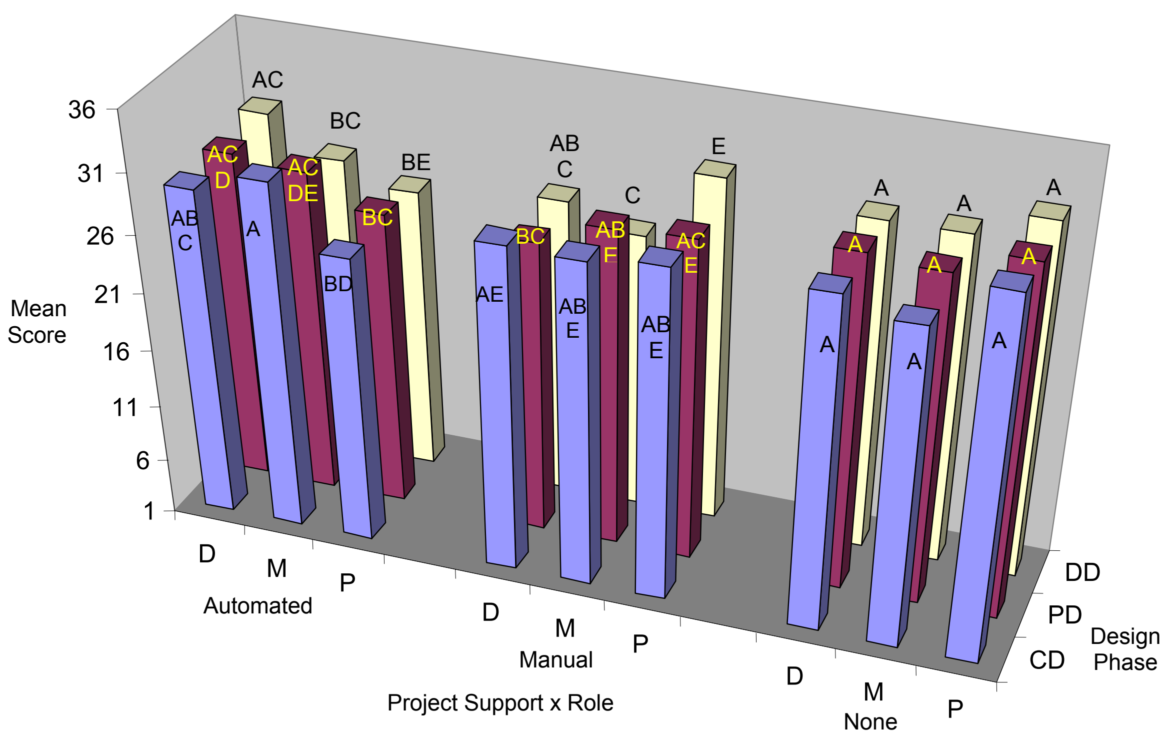


Figure A.15. 5 Comparisons of resources for the three-way interaction within each role



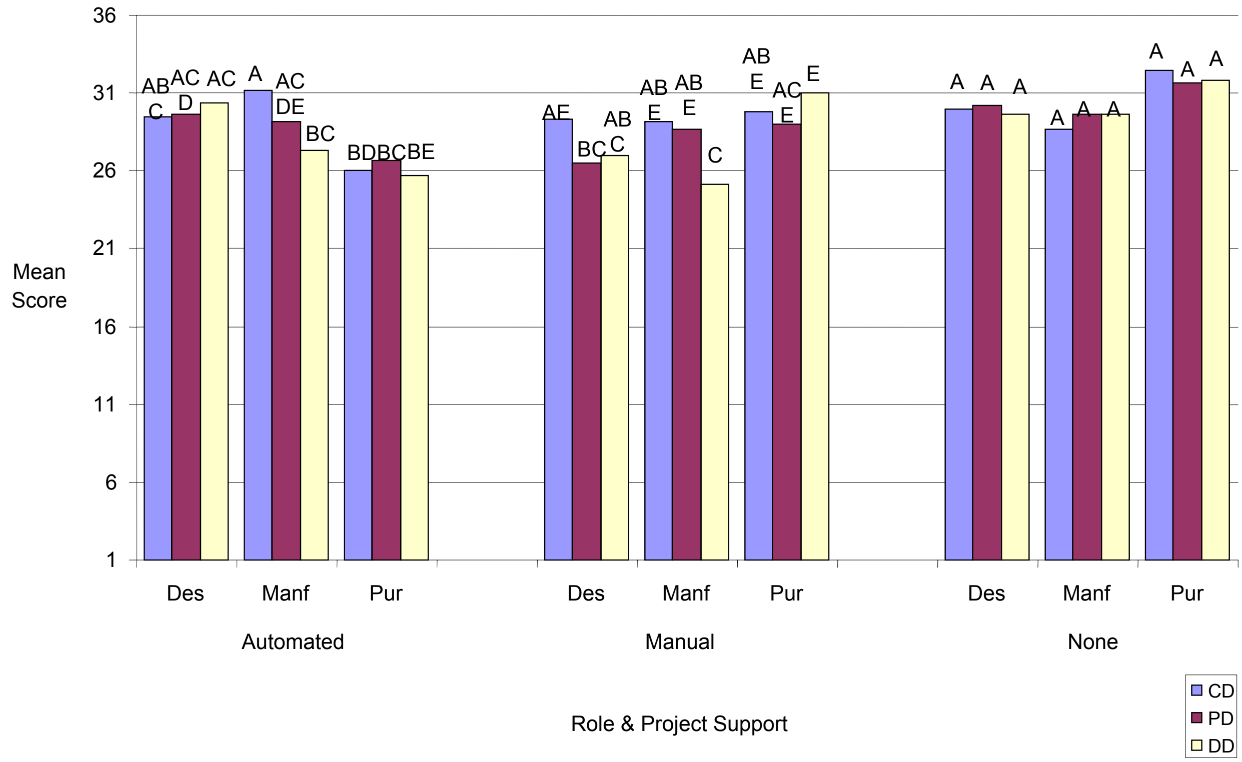


Figure A.15. 6 Comparisons of resources for the three-way interaction within project support levels

Table A. 15.3 Excessive work multiple comparisons for roles

Role changes while design phase and project support remain constant

	mean	CD Automated Manufacture	CD Automated Purchase
	mean	6.33	4.83
CD Automated Design	6.00	0.333	1.167*
CD Automated Manufacture	6.33		1.500**

	mean	CD Manual Manufacture	CD Manual Purchase
	mean	5.50	6.00
CD Manual Design	6.00	0.500	0.000
CD Manual Manufacture	5.50		0.500

	mean	CD None Manufacture	CD None Purchase
	mean	6.0	6.50
CD None Design	6.50	0.500	0.000
CD None Manufacture	6.0		0.500

	mean	PD Automated Manufacture	PD Automated Purchase
	mean	5.83	6.00
PD Automated Design	6.167	0.333	0.167
PD Automated Manufacture	5.83		0.167

	mean	PD Manual Manufacture	PD Manual Purchase
	mean	5.50	4.00
PD Manual Design	5.67	0.167	1.667**
PD Manual Manufacture	5.50		1.500**

	mean	PD None Manufacture	PD None Purchase
	mean	5.83	6.33
PD None Design	5.83	0.000	0.500
PD None Manufacture	5.83		0.500

	mean	DD Automated Manufacture	DD Automated Purchase
	mean	5.83	5.83
DD Automated Design	5.33	0.67	0.500
DD Automated Manufacture	5.83		1.167

	mean	DD Manual Manufacture	DD Manual Purchase
	mean	4.17	5.17
DD Manual Design	5.83	1.667*	0.667
DD Manual Manufacture	4.17		1.000

	mean	DD None Manufacture	DD None Purchase
	mean	5.67	6.17
DD None Design	5.17	0.500	1.000
DD None Manufacture	5.67		0.500

Design phase changes while role and project support remain constant

	mean	Design Automated PD	Design Automated DD
	mean	6.17	5.33
Design Automated CD	6.0	0.167	0.667
Design Automated PD	6.17		0.833

	mean	Design Manual PD	Design Manual DD
	mean	5.67	5.83
Design Manual CD	6.00	0.333	0.167
Design Manual PD	5.67		0.167

	mean	Design None PD	Design None DD
	mean	5.83	5.17
Design None CD	6.50	0.667	1.333*
Design None PD	5.83		0.667

	mean	Manufacture Automated PD	Manufacture Automated DD
	mean	5.83	4.67
Manufacture Automated CD	6.33	0.500	1.667**
Manufacture Automated PD	5.83		1.167

	mean	Manufacture Manual PD	Manufacture Manual DD
	mean	5.50	4.17
Manufacture Manual CD	5.50	0.000	1.333*
Manufacture Manual PD	5.50		1.333*

	mean	Manufacture None PD	Manufacture None DD
	mean	5.83	5.67
Manufacture None CD	6.00	0.167	0.333
Manufacture None PD	5.83		0.167

	mean	Purchase Automated PD	Purchase Automated DD
	mean	6.00	5.83
Purchase Automated CD	4.83	1.167**	1.000
Purchase Automated PD	6.00		0.167

	mean	Purchase Manual PD	Purchase Manual DD
	mean	4.00	5.17
Purchase Manual CD	6.00	2.000**	0.833
Purchase Manual PD	4.00		1.167

	mean	Purchase None PD	Purchase None DD
	mean	6.33	6.17
Purchase None CD	6.50	0.167	0.333
Purchase None PD	6.33		0.167

Project Support changes while role and design phase remain constant

		CD Design Manual	CD Design None
	mean		
	mean	6.00	6.5
CD Design Automate	6.00	0.000	0.50
CD Design Manual	6.00		0.500

		CD Manufacture Manual	CD Manufacture None
	mean		
	mean	5.50	6.00
CD Manufacture Automate	6.33	0.883	0.333
CD Manufacture Manual	5.50		0.500

		CD Purchase Manual	CD Purchase None
	mean		
	mean	6.00	6.50
CD Purchase Automate	4.83	1.167*	1.667**
CD Purchase Manual	6.00		0.500

		PD Design Manual	PD Design None
	mean		
	mean	5.67	5.83
PD Design Automate	6.17	0.50	0.333
PD Design Manual	5.67		0.167

		PD Manufacture Manual	PD Manufacture None
	mean		
	mean	5.50	5.83
PD Manufacture Automate	5.83	0.333	0.000
PD Manufacture Manual	5.50		0.333

		PD Purchase Manual	PD Purchase None
	mean		
	mean	4.00	6.33
PD Purchase Automate	6.00	2.000**	0.333
PD Purchase Manual	4.00		2.333**

		DD Design Manual	DD Design None
	mean		
	mean	5.83	5.17
DD Design Automate	5.33	0.500	0.167
DD Design Manual	5.83		0.667

		DD Manufacture Manual	DD Manufacture None
	mean		
	mean	4.17	5.67
DD Manufacture Automate	4.67	0.500	1.000
DD Manufacture Manual	4.17		1.500

		DD Purchase Manual	DD Purchase None
	mean		
	mean	5.17	61.7
DD Purchase Automate	5.83	0.667	0.333
DD Purchase Manual	5.17		1.000

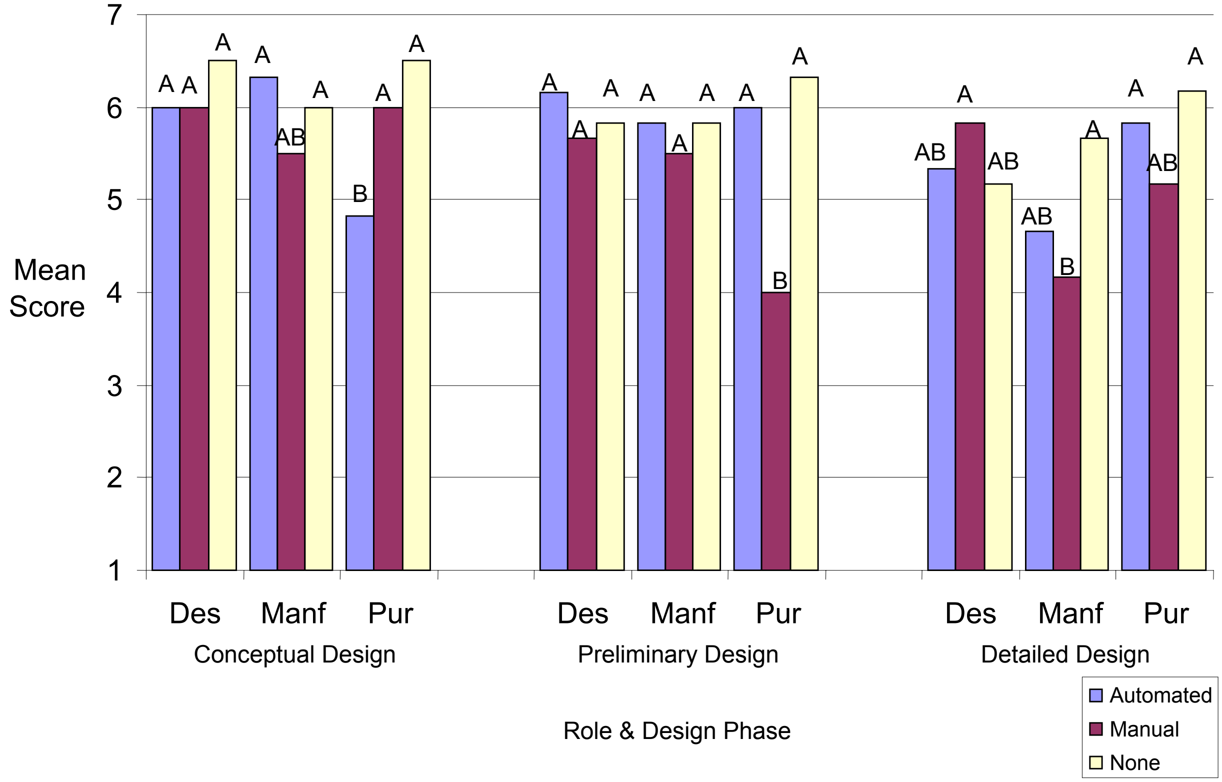


Figure A.15. 7 Comparison of excessive work for the three-way interaction within each design phase

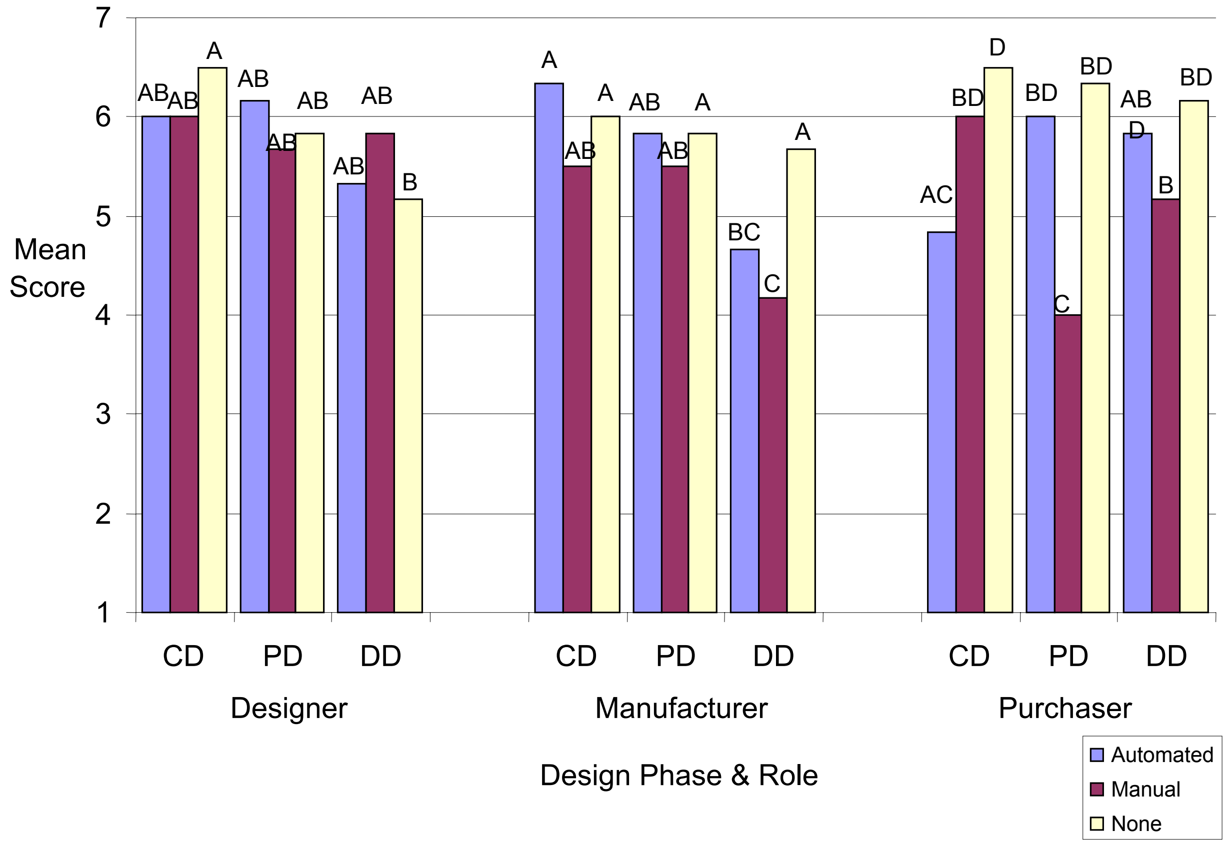


Figure A.15. 8 Comparing excessive work for the three-way interaction within each role

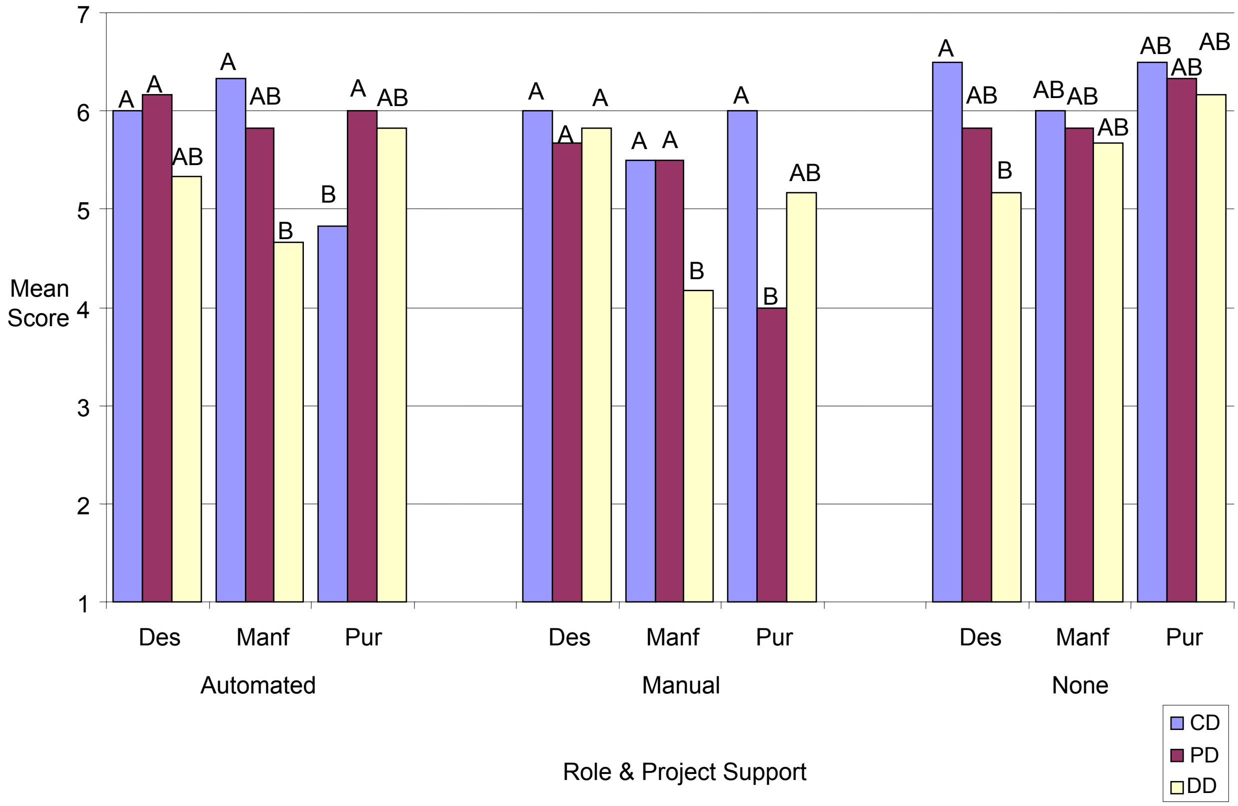


Figure A.15. 9 Comparing excessive work for the three-way interaction within project support levels

Appendix A.16 Supporting Variance Tables

In the analysis of time related comments, two variance groupings resulted in two different models with identical goodness of fits. The significant effects and interpretations were similar. The grouping by role is reported in this appendix while the grouping by design phase was reported in Chapter 5.

Table A. 16.1 Variance analysis for time related comments in groups

Source	**Effect**	**DF**	**Variance component**	**F value**	**Probability**
Between					
PS	Fixed	2		3.12	0.0545
R	Fixed	2		4.47	0.0191*
PS*R	Fixed	4		3.22	0.0241*
s/PS*R	Random	6	0.2713		
Within					
DP	Fixed	2		8.90	0.0005***
DP*PS	Fixed	4		0.08	0.9872
DP*R	Fixed	4		0.91	0.4631
DP*R*PS	Fixed	8		1.09	0.3850
Residual D	Random	35	0.4715		
Residual M	Random	23	1.6694		
Residual P	Random	32	0.7714		

*p<0.05

***p<0.001

Table A. 16.2 Multiple comparisons of the mean time-related comments based on phase

	mean	Preliminary design 1.40	Detailed design 0.84
Conceptual design	0.62	0.7778**	0.2222
Preliminary design	1.40		0.5556**

**p<0.01

Table A. 16.3 Multiple comparisons of the mean time-related comments based on role

	mean	Manufacturer 0.81	Purchaser 1.42
Designer	0.63	0.1852	0.7870**
Manufacturer	0.81		0.6019*

*p<0.05

**p<0.01

Table A. 16.4 Comparisons of time-related comments for project support and role

	mean	Auto Manf. 1.28	Auto Purchaser 1.31	Manual Designer 0.33	Manual Manf. 0.67	Manual Purchaser 2.36	None Designer 0.67	None Manf. 0.5	None Purchaser 0.58
Auto Designer	0.89	0.3889	0.4167	0.5556	0.2222	1.4722**	0.2222	0.3889	0.3056
Auto Manf.	1.28		0.0278	0.9444*	0.6111	1.0833*	0.6111	0.7778	0.6944
Auto Purchaser	1.31			0.9722*	0.6389	1.0556*	0.6389	0.8056	0.7222
Manual Designer	0.33				0.3333	2.0278**	0.3333	0.1667	0.2500
Manual Manf.	0.67					1.6944**	0.0000	0.1667	0.0833
Manual Purchaser	2.36						1.6944**	1.8611**	1.7778**
None Designer	0.67							0.1667	0.0833
None Manf.	0.5								0.0833

*$p < 0.05$

Appendix A.17 Agreement between Raters

A.17.1 Appendix Inter-rater Reliability between Group Members

Planning

The correlation coefficients for the scores between the group members during planning tended to be low with the exception of the performance rating and the supplemental questions regarding the planning tools.

Table A. 17.1 Correlation coefficients between observers for variables during planning

Variable	Correlation Coefficient
NASA TLX	0.0518
Mental	-0.1754
Physical	-0.3090
Temporal	0.5473
Performance	-0.9922
Effort	0.5150
Frustration	-0.0489
Job Satisfaction	0.1838
Job Satisfaction (group questions)	0.1869
Comfort	0.3072
Challenge	0.1745
Resources	-0.0343
Group Workload	
Value of group interaction	0.2722
Difficulty of group interaction	0.2954
Degree of cooperation	-0.1305
Overall group workload	-0.2844
Supplemental Questions	
Best	0.3604
Doubt	-0.0274
Ease of Use	0.6847
Efficient	0.7656
Effective	0.6468
Productive	0.6912
Satisfaction	0.9154

Design

The correlation coefficients for the scores between the group members during design tended to be low with the exception of the physical, temporal, and frustration ratings, the difficulty of group interaction rating, and the satisfaction with the planning and tracking tools.

Table A. 17.2 Correlation coefficients between observers for variables during conceptual design

Variable	Correlation Coefficient
NASA TLX	0.2302
Mental	-0.1769
Physical	0.6518
Temporal	0.5089
Performance	-0.1953
Effort	0.2554
Frustration	0.5870
Job Satisfaction	0.3704
Job Satisfaction (group questions)	0.4051
Comfort	0.3675
Challenge	0.1647
Resources	0.3302
Group Workload	
Value of group interaction	0.4226
Difficulty of group interaction	0.6191
Degree of cooperation	0.2757
Overall group workload	0.2800
Supplemental Questions	
Doubt	0.4448
Ease of Use	0.4560
Efficient	0.3661
Effective	0.0846
Productive	0.3490
Satisfaction	0.6005

Reflective

The correlation coefficients for the scores between the group members during design tended to be low with the exception of the physical and frustration ratings, job satisfaction and comfort, and the supplemental questions (with the exception of ease of use).

Table A. 17.3 Correlation coefficients between observers for variables upon reflection

Variable	Correlation Coefficient
NASA TLX	-0.2648
Mental	0.3149
Physical	0.6968
Temporal	-0.1843
Performance	0.4284
Effort	-0.0096
Frustration	0.5140
Job Satisfaction	0.6200
Job Satisfaction (group questions)	0.6096
Comfort	0.5652
Challenge	0.3972
Resources	0.5426
Group Workload	
Value of group interaction	0.1112
Difficulty of group interaction	0.2650
Degree of cooperation	0.4034
Overall group workload	-0.0472
Supplemental Questions	
Best	0.6961
Liked	0.8061
Meet/exceeded objectives	0.8431
Ease of Use	0.2813
Productive	0.5437
Satisfaction	0.6283
Schedule	0.6632
Budget	0.6191

A.17.2 Agreement between Observers

<u>Group Workload Assessed by External Observers</u>

Because two observers were used in the external observations of group workload, the level of rater agreement needed to be determined. SPSS was used to calculate intra-rater correlation coefficients based on consistency between the observations.

Table A. 17.4 contains a summary of the correlation coefficients for the observations categorized by planning, during the design process, and reflection over the entire design project. The coefficient that was the most troubling was coefficient for the value of group interaction during the design process. While an average of the two observers was used in the analysis, the results need to be interpreted keeping in mind the lack of agreement and that what was tested tended to be a compromise between two diverse opinions.

Table A. 17.4 Correlation coefficients between observers for group workload scales

Variable	Correlation Coefficient
Planning	
Value of group interaction	0.5089
Difficulty of group interaction	0.5245
Degree of cooperation	0.4286
Overall group workload	0.6388
Design Process	
Value of group interaction	0.2447
Difficulty of group interaction	0.4796
Degree of cooperation	0.3492
Overall group workload	0.6276
Reflective	
Value of group interaction	0.8598
Difficulty of group interaction	0.5222
Degree of cooperation	0.5188
Overall group workload	0.6684

Critical Team Behaviors Assessed by External Observers

As with the evaluation of the group workload, because two observers were used, the level of agreement between the two observers was tested. Because the level of agreement determined between observation counts, not scale agreements, Pearson's correlation was reported. As noted in Table A. 17.5, there were some unusually strong agreements between the observers, and the reliability of the observations should be in question. This was probably due to a logistical issued in which both of the observers were in the same room making their observations at the same time. While they were not sharing the same work space, motions could be easily be observed. The average between the observers was used in the analysis.

Table A. 17.5 Pearson correlation between observers

Variable	Designer	Manufacturer	Purchaser
Planning			
Positive	0.881	0.760	0.903
Negative	0.949	0.973	0.837
Acceptance	1.000	1.000	0.816
Adaptability	0.775	0.775	0.700
Communication	0.898	0.775	0.824
Cooperation	0.581	0.834	0.906
Coordination	0.888	0.960	0.872
Giving Feedback	0.670	0.352	0.507
Team Spirit and Morale	1.000	0.973	0.479
Design Process			
Positive	0.893	0.848	0.845
Negative	0.836	0.834	0.892
Acceptance	0.668	0.873	1.000
Adaptability	0.913	0.902	0.890
Communication	0.776	0.907	0.866
Cooperation	0.829	0.741	0.909
Coordination	0.868	0.871	0.808
Giving Feedback	0.715	0.715	0.781
Team Spirit and Morale	0.895	0.851	0.881

Appendix A.18 Correlations between Performance and Demographics

Table A. 18.1 Correlations between design performance and demographics

	CE	SE	Reliable	Lifecycle	Design Cost	Material Cost	Errors
Age	-0.126	-0.074	0.100	0.062	-0.039	0.070	0.278
GPA	0.045	-0.173	-0.435**	-0.050	-0.344*	0.202	0.010
Year	0.034	0.102	-0.097	-0.173	-0.217	-0.056	0.231
No Projects	-0.084	-0.251	-0.145	-0.076	-0.080	-0.036	0.710**

Table A. 18.2 Correlations between planning performance and demographics

	Gantt Chart	Scoping Document	Planning Time
Age	-0.269	0.157	0.392
GPA	0.377	-0.142	-.491*
Major	0.004	-0.135	0.358
Year	0.118	0.033	0.338
No Projects	-0.033	-0.007	0.167

Appendix A.19 Job Satisfaction Reliability

The discussion of job satisfaction would not be complete without checking the reliability of the factors: comfort, challenge, and resources. Cronbach's alpha was calculated for each factor for each set of questions: planning, design, and upon reflection, and the results are reported in Table A. 19.1. The reliabilities ranged from a low of 0.3504 (for comfort assessed during planning) to a high of 0.7728 for resources assessed reflectively for the group data. While the comfort values were low in several situations, especially for planning, in general the reliabilities were comparable to those reported by Quinn and Sheppard (1974) for larger populations (the exception was comfort during planning). While the measure used to capture job satisfaction was not designed to capture short term job satisfaction, these results supported the use the faceted measure as part of a controlled, short term project.

Table A. 19.1 Reliability for comfort, challenge and resources

Factor	Reliability for average of groups and individuals	Reliability for group data (roles)
Planning		
Job Satisfaction	0.8112	0.7574
Comfort	0.3504	0.4998
Challenge	0.6802	0.6194
Resources	0.6784	0.5378
Design		
Job Satisfaction	0.8424	0.8305
Comfort	0.5890	0.6020
Challenge	0.6227	0.6822
Resources	0.7192	0.6899
Reflective		
Job Satisfaction	0.8908	0.8593
Comfort	0.6401	0.5140
Challenge	0.7878	0.7490
Resources	0.7519	0.7728

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