Junkyard Wars:
Building Complex Machinery out of Junk

CS 6010: Principles of Design
Fall 2003

Kori Bevis
Jeanie Miskelly

Introduction

Junkyard Wars is a television program on The Learning Channel (TLC) that pits two teams against each other to build a very technical device in a 10 hour time limit. These devices are very unique and also very technically complicated; past devices have included hydrofoils, trebuchets, amphibious vehicles, and dune buggies. Besides the 10 hour time limit, an additional constraint is that each team may only use the materials that can be found on the show's set – a junkyard. At the end of the two hours, the two teams test their devices in a contest that is designed to test the functionality of the product. The team whose product has a superior performance wins the challenge. The show has a tournament style format, so winning the challenge means advancing to the next level of play.

Junkyard Wars, as well as its British counterpart Scrapheap Challenge, is produced by RDF Media. The show has been run for approximately 6 seasons in each country. The first series was called 'Scrapheap' and aired only in the United Kingdom (UK). The second (and subsequent) series was called 'Scrapheap Challenge' and also aired in the UK. American broadcaster TLC got hold of the show and re-named it 'Junkyard Wars'. TLC has since aired all of the shows – both British and American (Junkyard Wars Online FAQ, 2003). Most recently, the show has been given yet another name, "Junkyard Mega Wars", which boasts that it is "new and improved". Instead of being run in a tournament style format, there are two permanent team captains ("Crash" and "Bowser").

Research Questions

Goel and Pirolli (1991) performed 12 protocol analyses on expert designers in architecture, mechanical engineering, and instructional design. The experts were given a task in their knowledge domain and were asked to think aloud while designing. Through this research, they outline invariants that compose design problem spaces. Further, they did protocol analysis on nondesign tasks to see how they differ from design tasks. In thinking about the various constraints on the design problem of building a specified device out of junk, we wonder if there is a common design process that is usually used by the design teams. We used a simpler, modified version of Goel and Pirolli's coding scheme to examine the design processes used by the teams on Junkyard Wars. Additionally, we were interested if certain elements of the process, such as allocating additional time for planning or evaluating, preplanning alternative designs, or having flexibility in the design, correspond to creating a successful or unsuccessful design.

Method

McCracken (2003) outlines three common methods for conducting research on design learning: In Situ Observation, Retrospective Interviews, and Protocol Analysis. Although he focuses on design learning, these methods can be applied to research on any cognitive process. We used the descriptions of these approaches as a guide in designing our research practices.

We initially intended to contact participants of Junkyard Wars and conduct retrospective interviews. We wanted the participants to recall what they were thinking during particular situations. We would ask the participants questions that would give further insight into their thoughts during the design activity. Unfortunately, we were unsuccessful in contacting any participants, so we attempted to locate any local clubs that did similar design competitions. We were unable to find any appropriate groups, so we focused our efforts into doing *in situ* observation. We videotaped 6 episodes in the 'Junkyard Wars' series, allowing us to observe a total of 12 teams. Four episodes were the British version (Amphibious Motorcycles, Backpack Cars, Bomb Disposer, Wheelie Cars) and two episodes were the American version (Hot Rods, Precision Shooting). Following are the task descriptions for each episode.

Amphibious Motorcyles – Teams were asked to build a motorbike that could be driven on land and in water.

Backpack Cars – Teams were asked to build a car that could break down into parts and fit into four back packs.

Bomb Disposer – Teams were asked to build remote control vehicles that can cut through electrified fencing, move toxic waste into a canister, and disarm unstable bombs that are set to explode if tilted.

Wheelie Cars – Teams were asked to build cars that could lift and drive with the front wheels off the ground through an obstacle course and in a head-to-head race.

Hot Rods – Teams were asked to build a hot rod dragster and race down a 1/8th mile dragstrip.

Precision Shooting – Teams were asked to build contraptions that can shoot down and pop mylar balloons.

Through observing the design of artifacts from junk in the episodes, we tried to construct understandings of the participants' design behaviors. Through the comments made and actions taken by the participants as well as commentary given by the hosts of the show, we could observe or infer steps in the design process. We transcribed each episode and separated the comments by teams. The transcriptions were then encoded using our predetermined coding scheme.

During the episodes, a host would announce how much time remained for the participants to complete their designs. The announced times were not always consistent, but allowed us to break the design process into four segments. For each segment, we determined what percentage of time each team spent on the encoded categories.

Limitations

The biggest limitation of observing the taped programs is that they are, of course, television programs. Because they are television programs, the content is edited and we do not get to see exactly what went on. To make 1 hour of Junkyard Wars (45 minutes without commercials) it takes 140 hours of tape (Junkyard Wars Online FAQ, 2003); so, we are missing at least 139 hours of activity. From what we could tell, it seemed that the Problem Formulation and Overall Design phases were generally not shown in much detail. The show focused its time on the Sub-Problem Solution and Evaluation phases, probably because those are the phases that are most entertaining to the show's audience. However, even those phases which took up most of the show's air time were also heavily edited.

An additional limitation that we found when attempting to code the data is that it was hard to judge how much time had elapsed. Throughout the show, the hosts will announce to the teams how much time they have left to work, however, these announcements are not made at consistent points from show to show. Therefore, we would end up with shows that had announcements at different times. We were forced to use our best judgment in estimating the passage of time.

Analysis

After taping the shows, we watched and transcribed each of them. We then coded statements in the transcriptions according to the following coding scheme:

Coding Name	Description of Criteria	Example Statement
Problem Formulation	Statements that clarify the exact problem to be solved	"We have between 20 and 200 targets. The targets are 1.5 – 3 feet in diameter. Maximum range to target – 50 meters."
Overall Design	Statements that talk about the general design, without detail	"You could have a long arm that goes out. Sometimes they call it a master-slave system."
Decomposition	Statements that describe how or give evidence that the problem has been broken down into smaller sub-problems	"Rosanna has been given the task of fabricating the release mechanism for the crossbow."
Sub-Problem Solution	Statements giving evidence that the team has found a way to solve one of the smaller sub-problems	"After some work, the team has found a van they think will make the ideal platform for Henk's complex arm."
Evaluation	Statements describing the qualities of the machine when put to the test	"It has a little bit of a kick, but it didn't shoot very well."
Prediction	Statements indicating how well the machine is expected to work	"If theirs sticks together, they could be runaway winners, but I don't think it will."

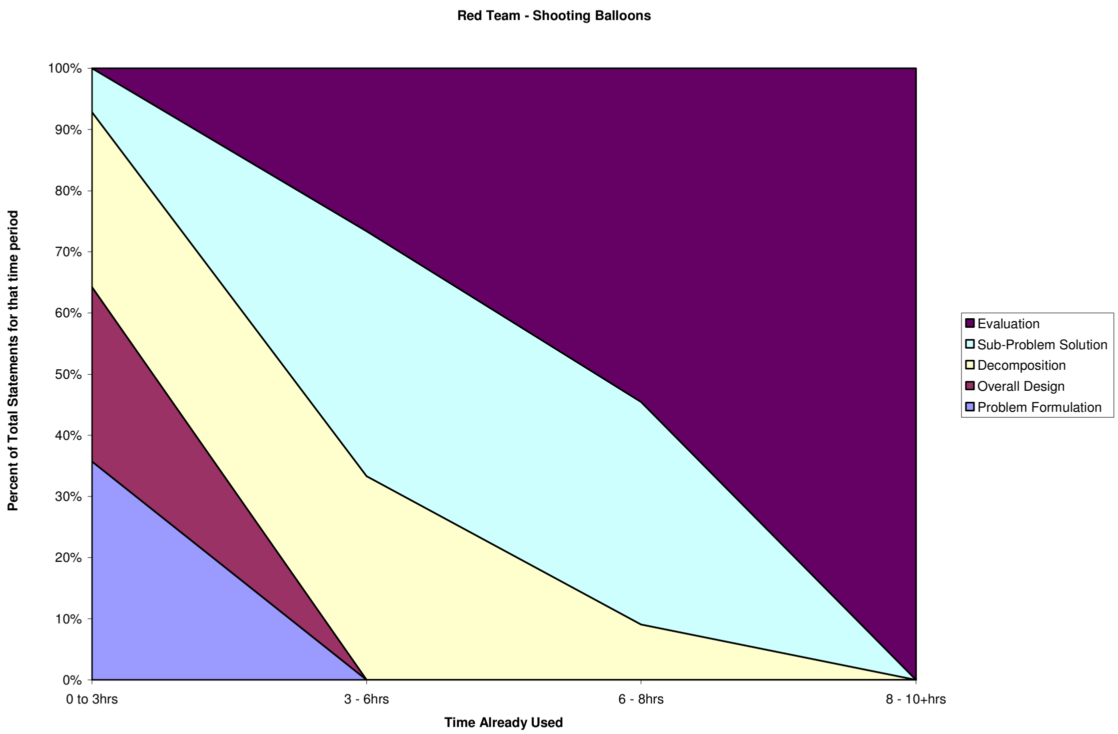
We coded the transcription of one team together so that we could establish guidelines and standards for coding, and attempt to have some form of inter-rater reliability. We then split the task of encoding the other remaining 11 teams. Additionally, we consulted with each other regarding difficulties during the coding process so that we might resolve problems together.

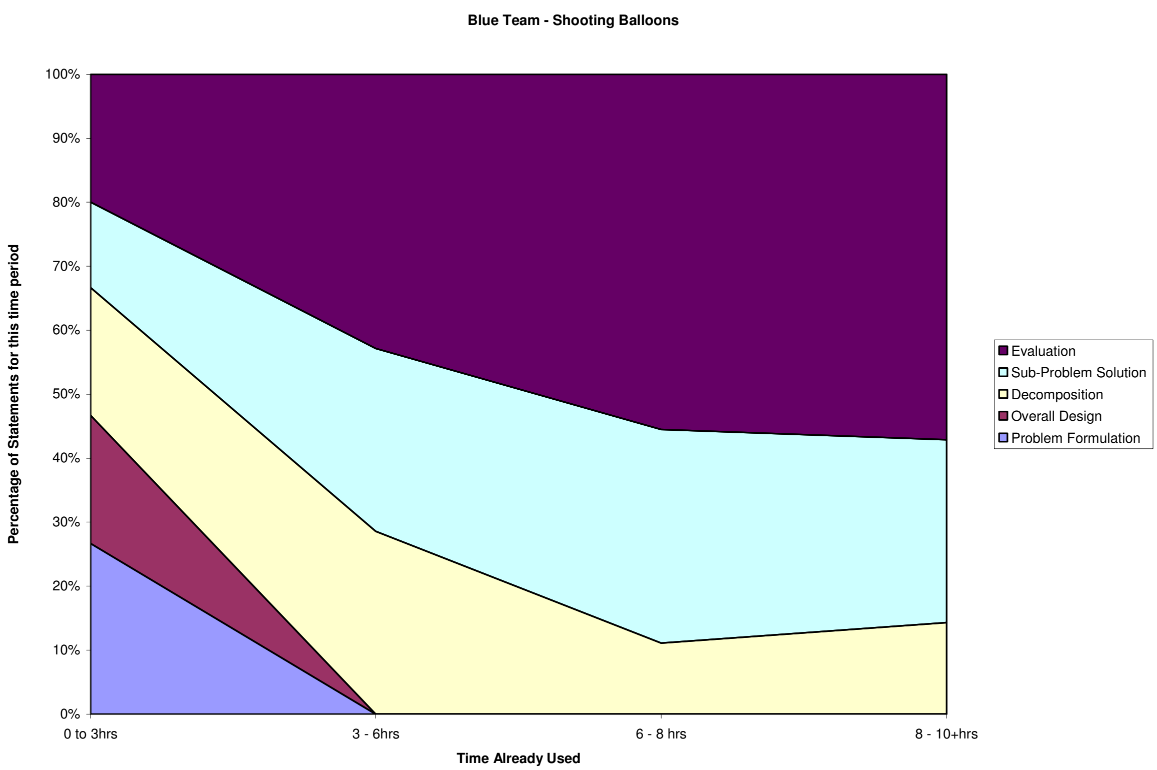
We then analyzed the data by breaking each transcription into 4 time periods that we judged to be approximately equal. We counted the number of each type of statement in each period and inputted the data into an Excel spreadsheet. We made graphs for each team, as well as graphs that indicated the averaged numbers of statements for winning, losing, and failing teams.

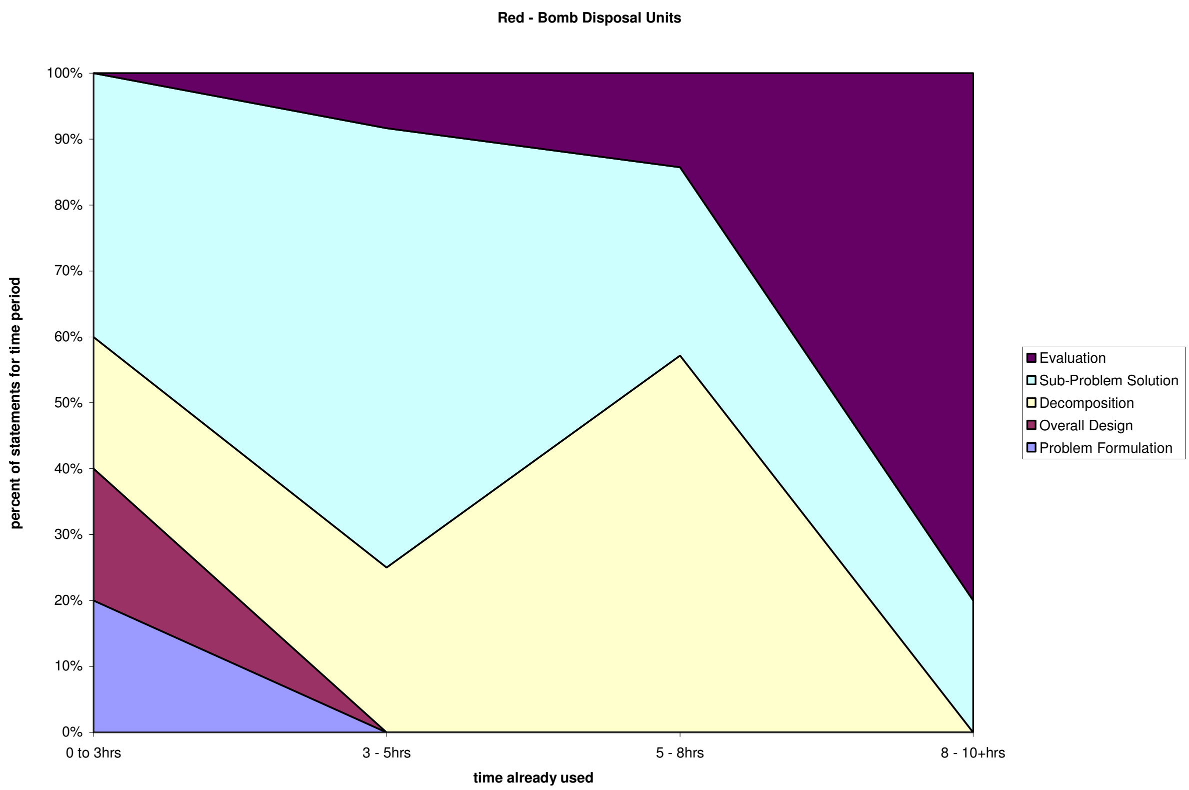
Results

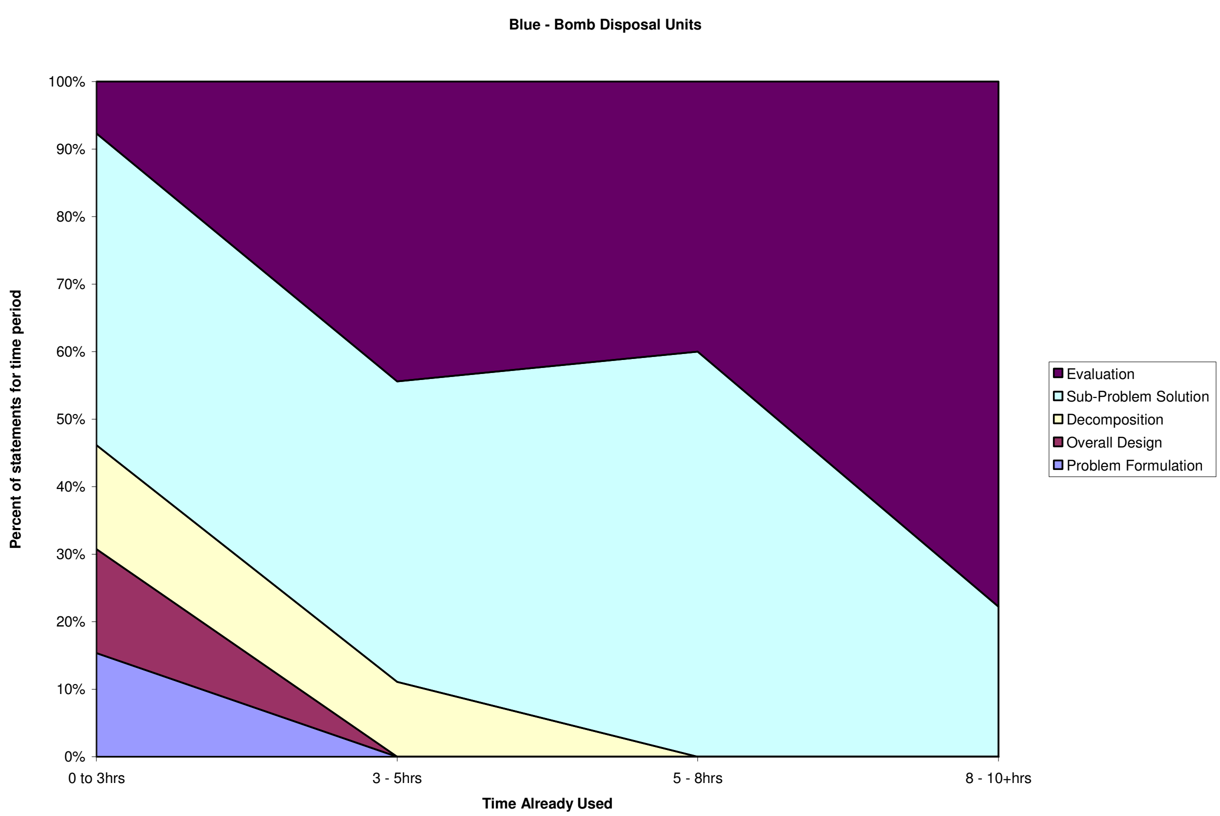
Individual Team Graphs
Pages 6 – 11 show the graphs of the number of each type of statement encoded for each team. As is visible from these graphs, it seems that all of the teams use a very similar (if not practically identical) design process. The most notable similarities include:

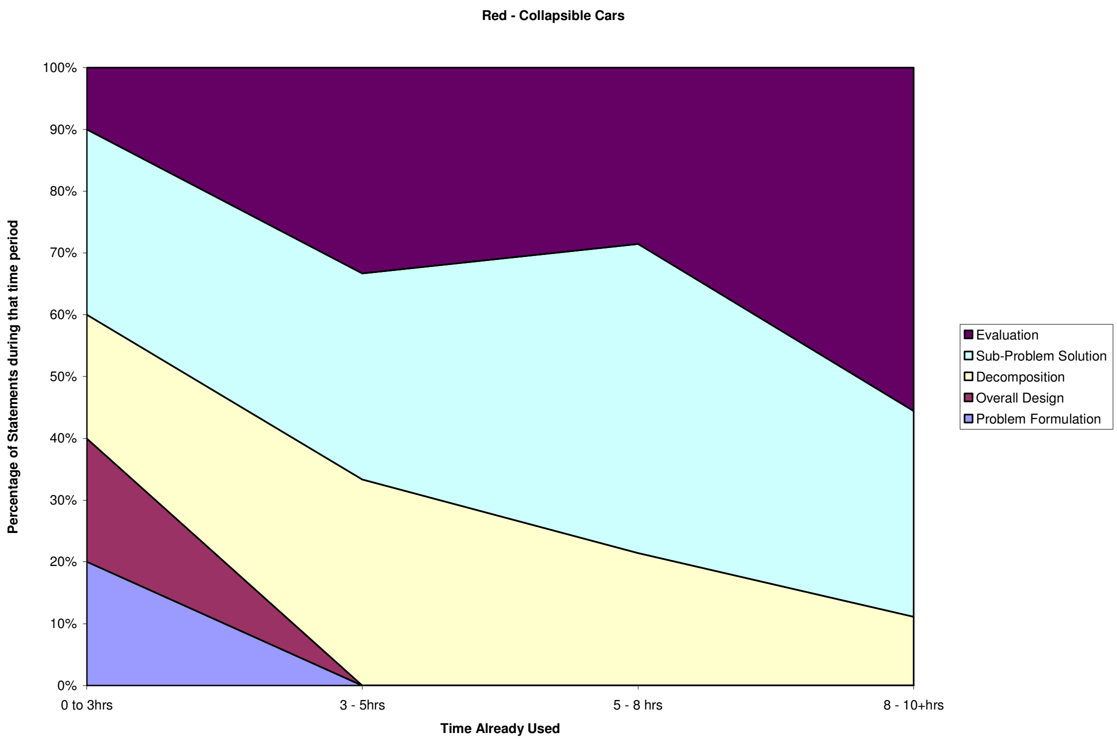
- The teams all perform Problem Formulation and Overall Design almost exclusively during the period between the first and second time markers.
- Decomposition, Sub-Problem Solution, and Evaluation generally occur throughout the graph (possibly because these phases are the ones most interesting to the television audience)

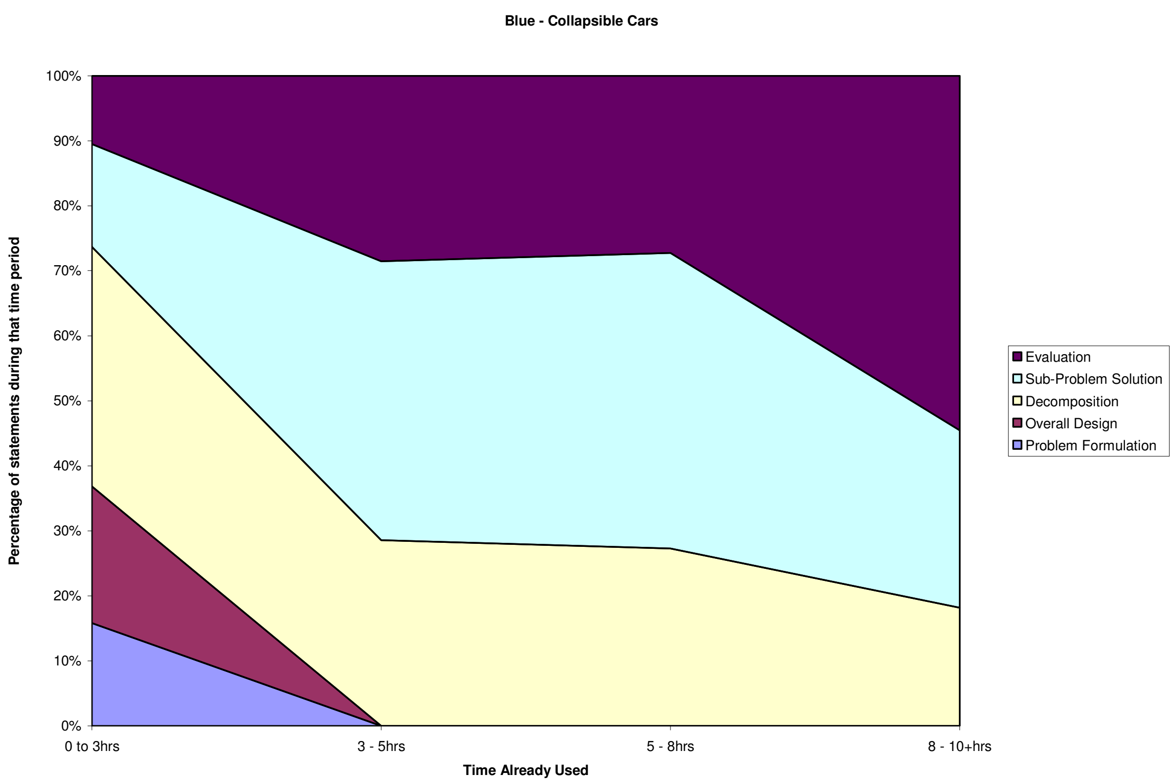

Red Team - Shooting Balloons
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of Total Statements for that time period
0 to 3hrs
3 - 6hrs
6 - 8hrs
8 - 10+hrs
Time Already Used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Blue Team - Shooting Balloons
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of Statements for this time period
0 to 3hrs
3 - 6hrs
6 - 8 hrs
8 - 10+hrs
Time Already Used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Red - Bomb Disposal Units
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
percent of statements for time period
0 to 3hrs
3 - 5hrs
5 - 8hrs
8 - 10+hrs
time already used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Blue - Bomb Disposal Units
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of statements for time period
0 to 3hrs
3 - 5hrs
5 - 8hrs
8 - 10+hrs
Time Already Used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Red - Collapsible Cars
Percentage of Statements during that time period
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 to 3hrs
3 - 5hrs
5 - 8 hrs
8 - 10+hrs
Time Already Used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Blue - Collapsible Cars
Percentage of statements during that time period
100%
90%
80%
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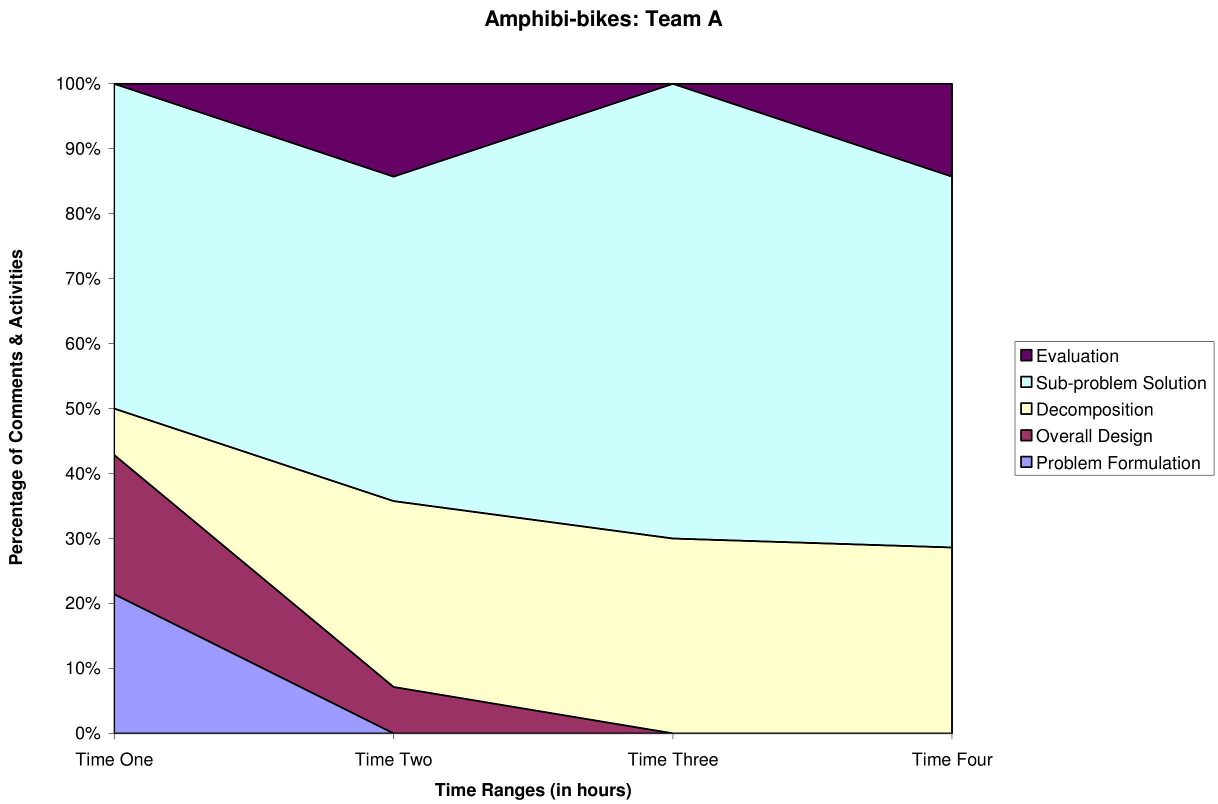
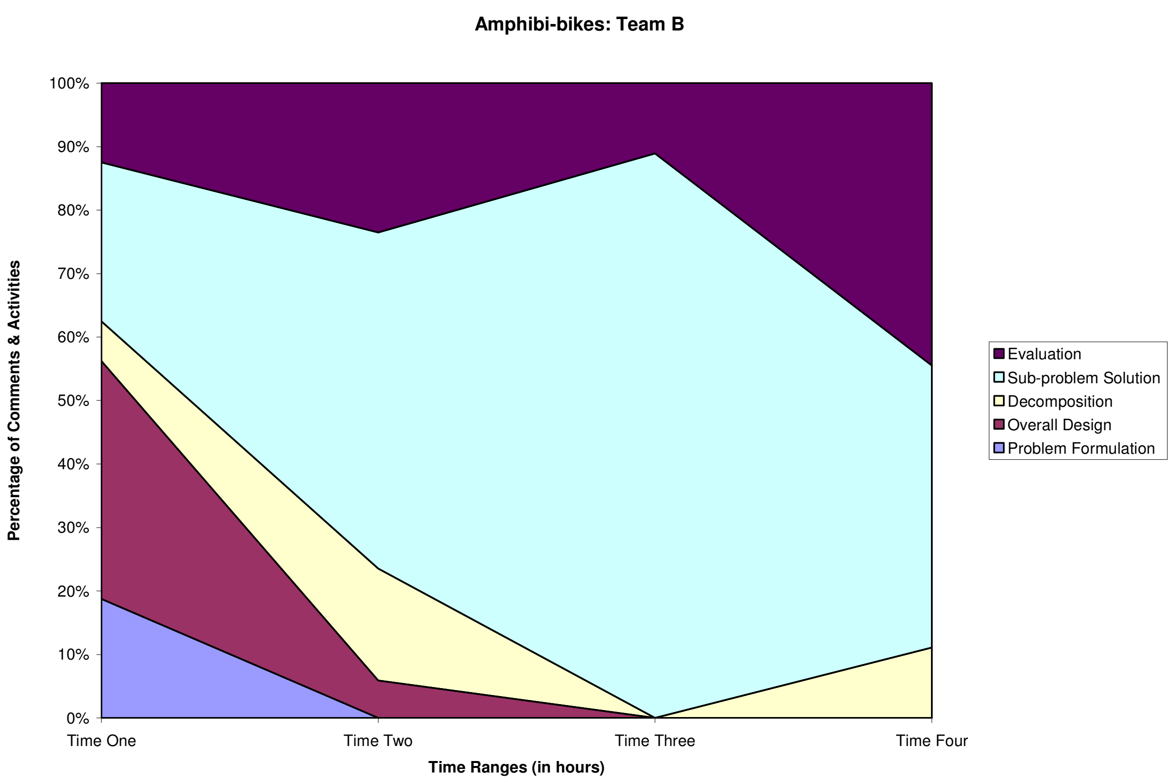
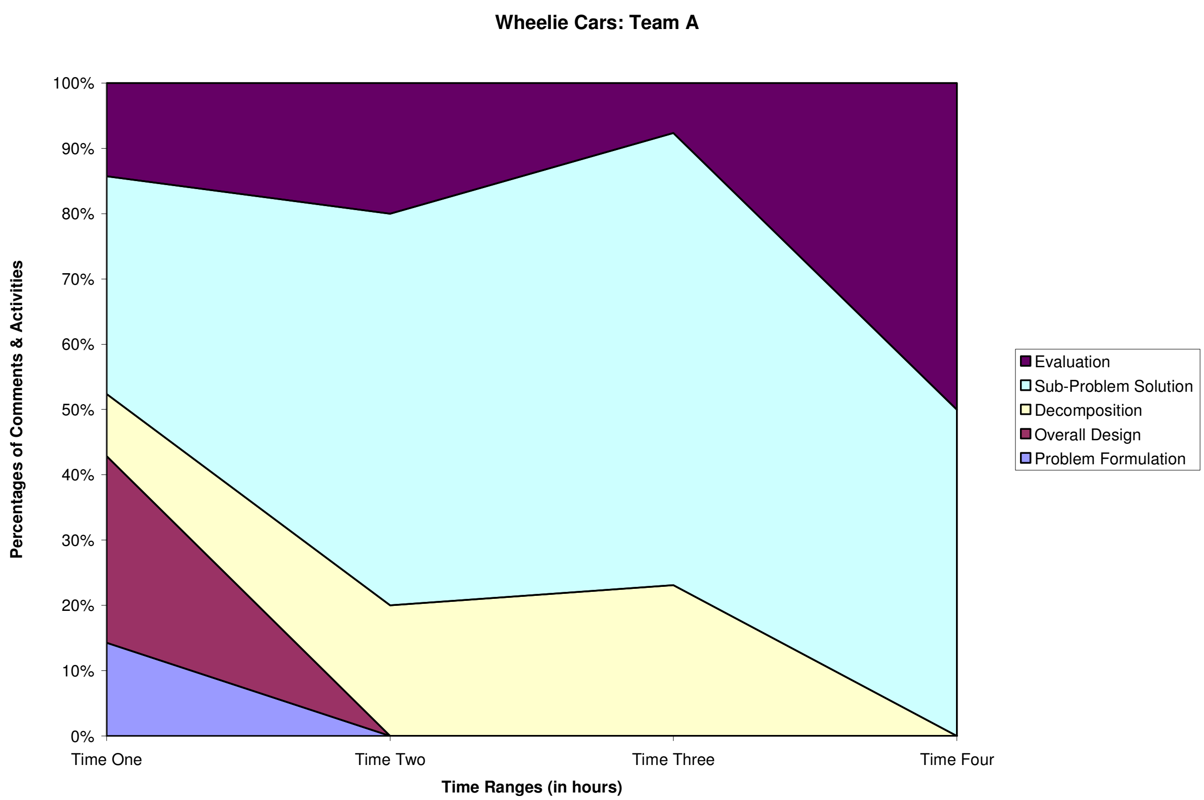
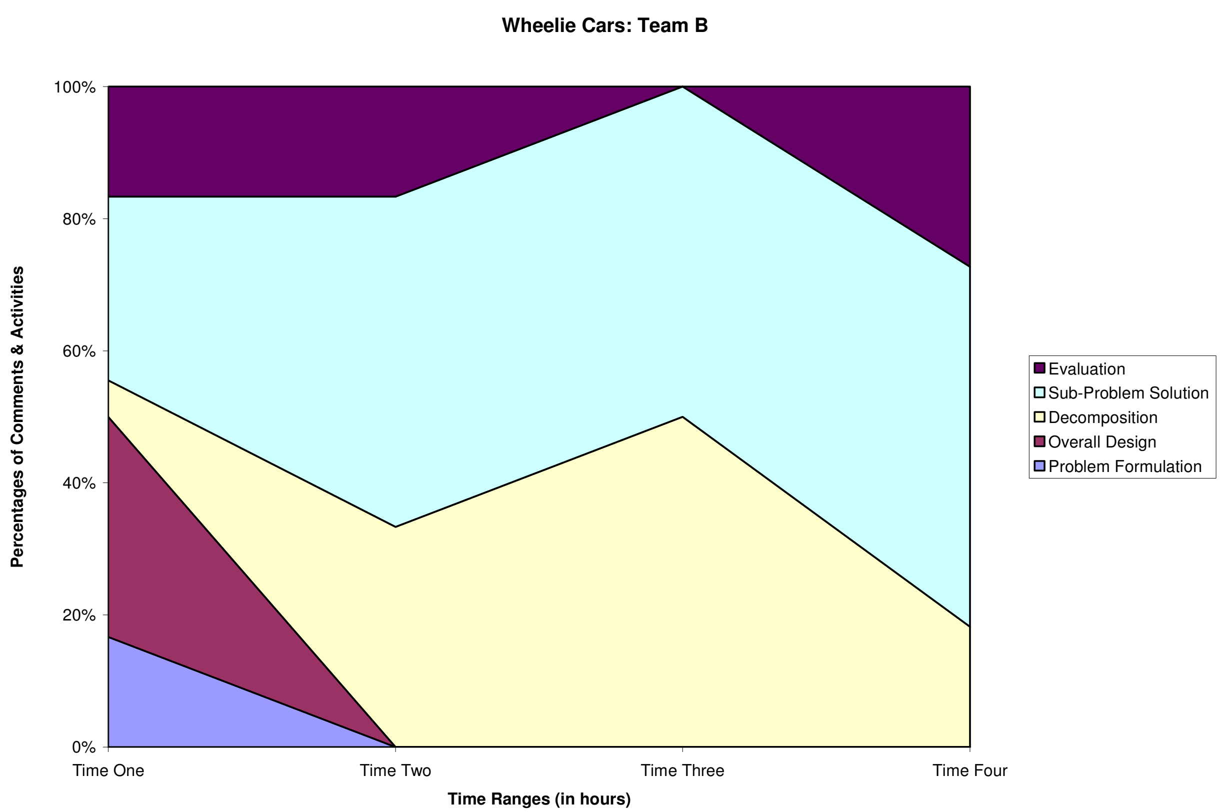
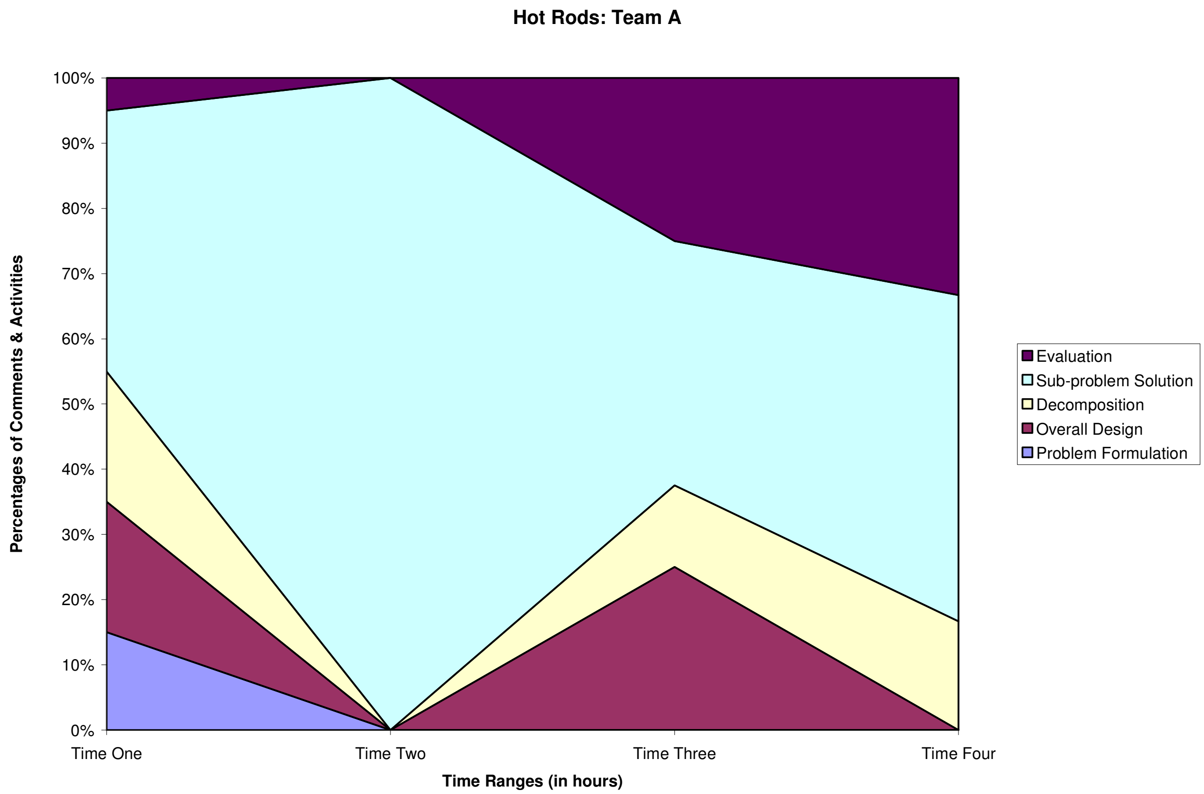
0 to 3hrs
3 - 5hrs
5 - 8hrs
8 - 10+hrs
Time Already Used
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation

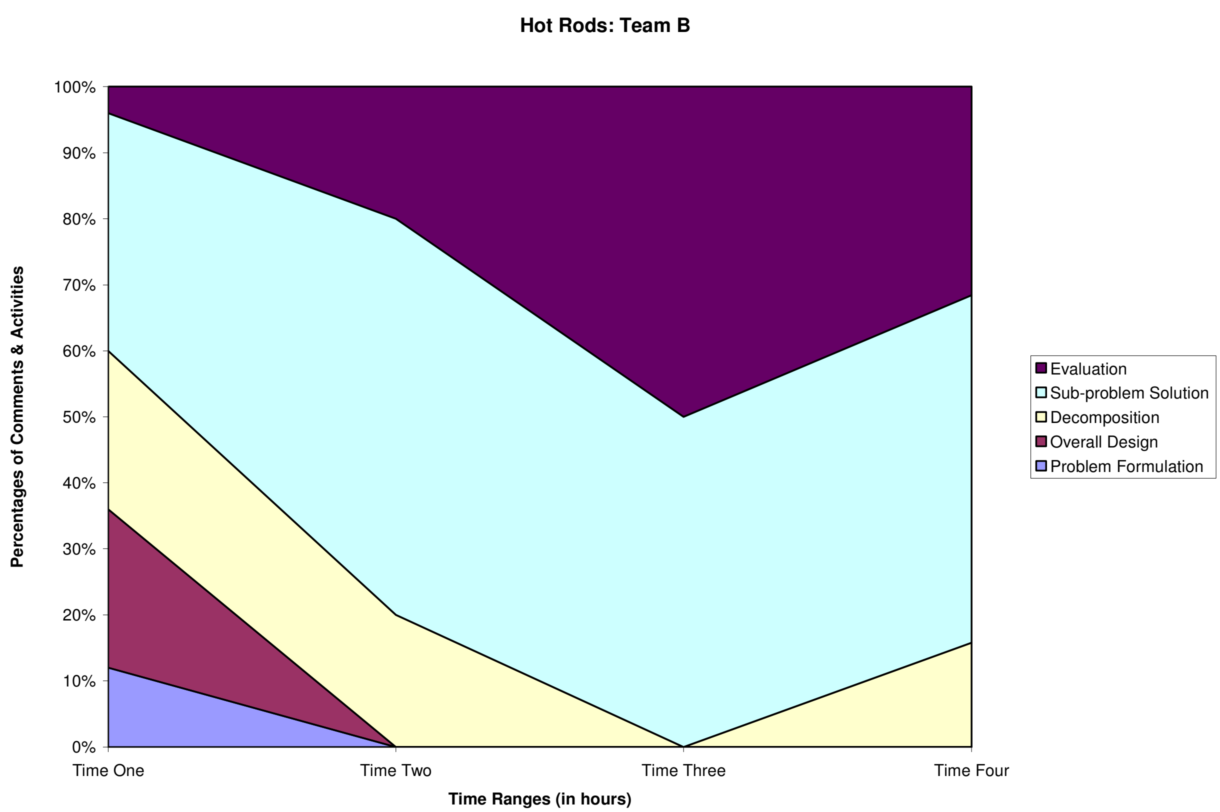

Amphibi-bikes: Team A
Percentage of Comments & Activities
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-problem Solution
Decomposition
Overall Design
Problem Formulation


Amphibi-bikes: Team B
Percentage of Comments & Activities
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-problem Solution
Decomposition
Overall Design
Problem Formulation

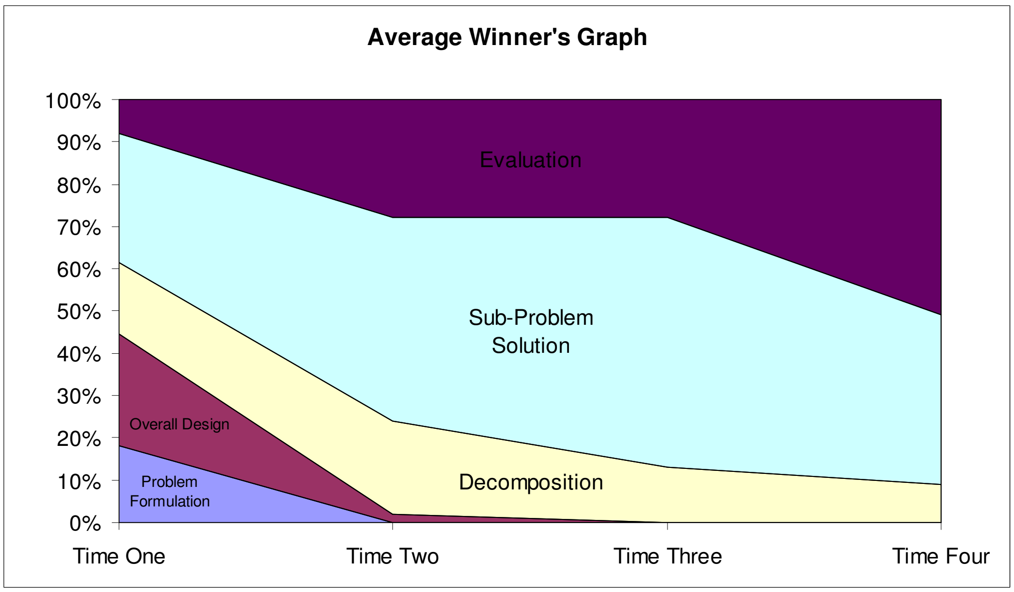

Wheelie Cars: Team A
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentages of Comments & Activities
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation

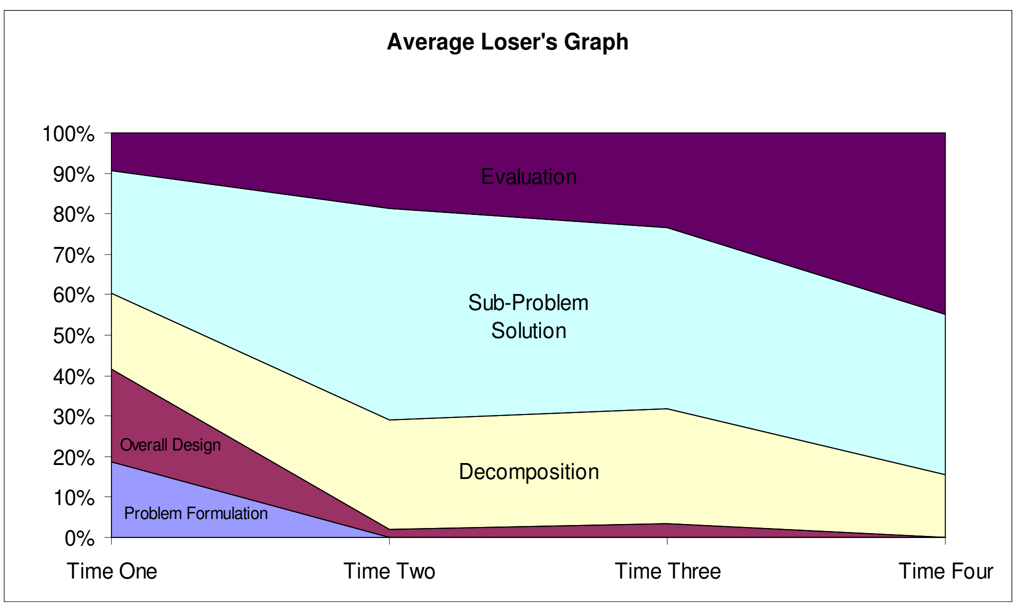

Wheelie Cars: Team B
100%
80%
60%
40%
20%
0%
Percentages of Comments & Activities
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-Problem Solution
Decomposition
Overall Design
Problem Formulation


Hot Rods: Team A
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentages of Comments & Activities
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-problem Solution
Decomposition
Overall Design
Problem Formulation


Hot Rods: Team B
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentages of Comments & Activities
Time One
Time Two
Time Three
Time Four
Time Ranges (in hours)
Evaluation
Sub-problem Solution
Decomposition
Overall Design
Problem Formulation

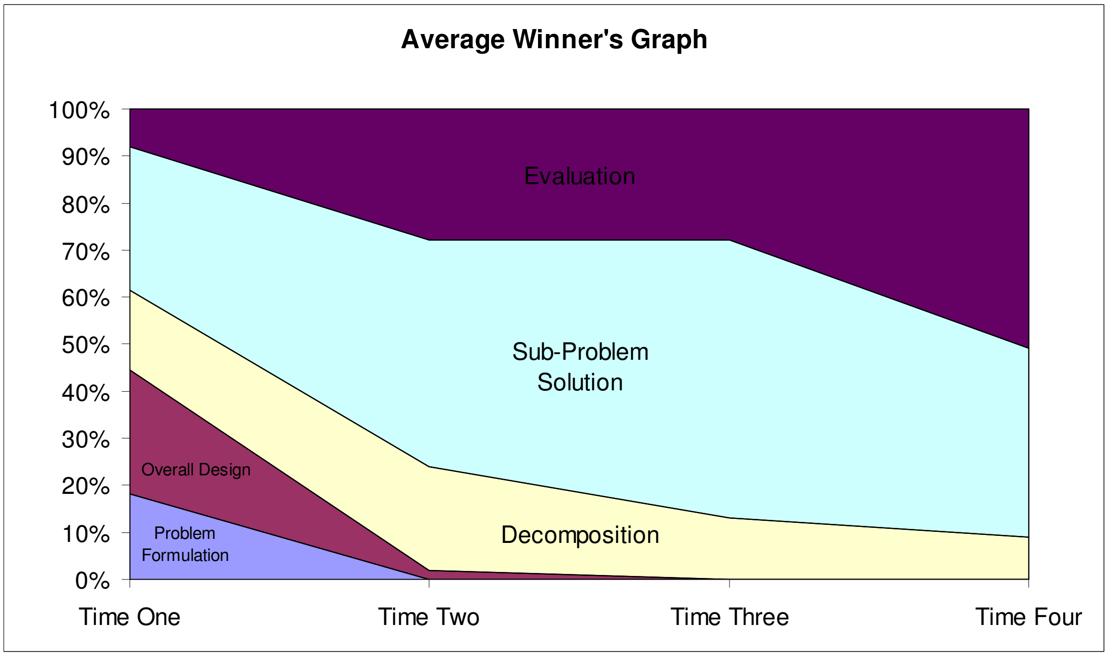
Winners versus Losers
These graphs show the average number of statements in each category (essentially the average design process) for the teams that either won or lost the end challenge. As is evident, the graphs are nearly identical. This shows that winning or losing a challenge doesn't seem to correspond to any change in design process. However, many of the challenges were nearly tied – sometimes only milliseconds separated winners from losers. In these instances, we interpret that the "losing" teams are not actually losers from a design standpoint. They adequately solved the design problem, it just happened that the other team's design worked a little better.

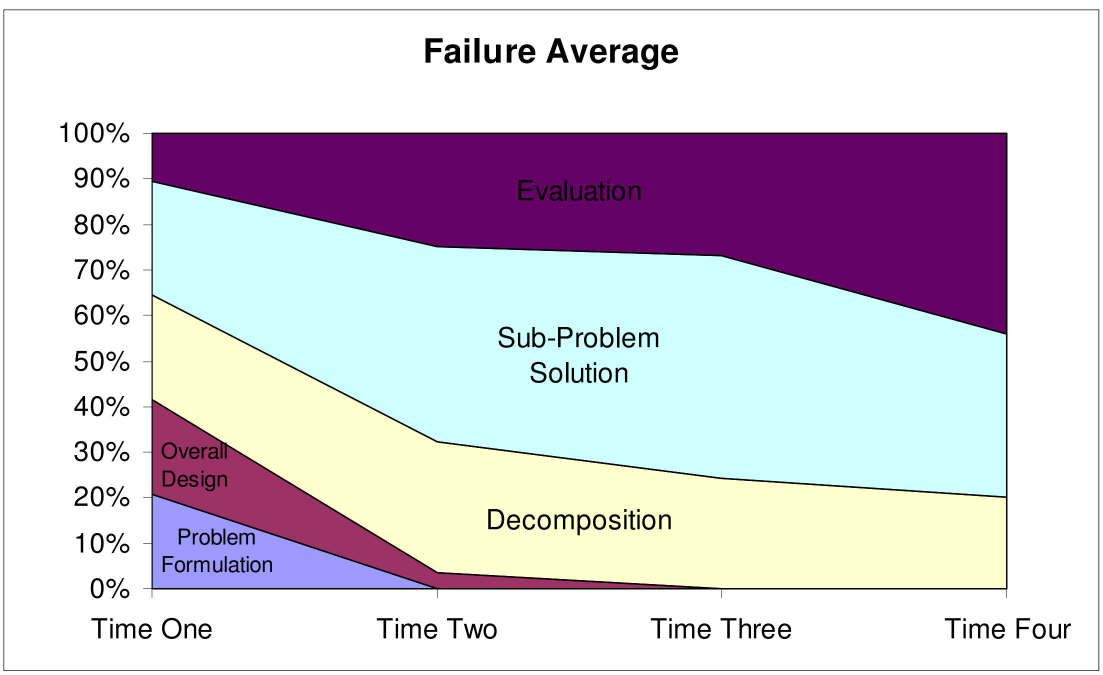




Winners versus Failures

There were three cases where the team's design did not perform to specification, or was not able to complete the challenge. We termed those "design failures", and thought it would be interesting to compare the graph of the failed teams to that of the teams that won the challenge. Unfortunately, as is shown by the two graphs, there appears to be no significant difference in the process of these two classes of teams.





Percentage of Comments and Activities

Figure 1 shows that the problem structuring phase (Problem Formulation) accounted for 7% of the comments and activities observed. Goel and Pirolli's research found that this phase accounted for nearly 25% of the statements in design protocols (1991). In contrast, nondesign protocols devoted 0.3% of statements to problem structuring. Because of the ill-structured nature and complexity of the design problems, we suspect that the Junkyard Wars participants devoted a similar amount of time, but that this content was edited for television.

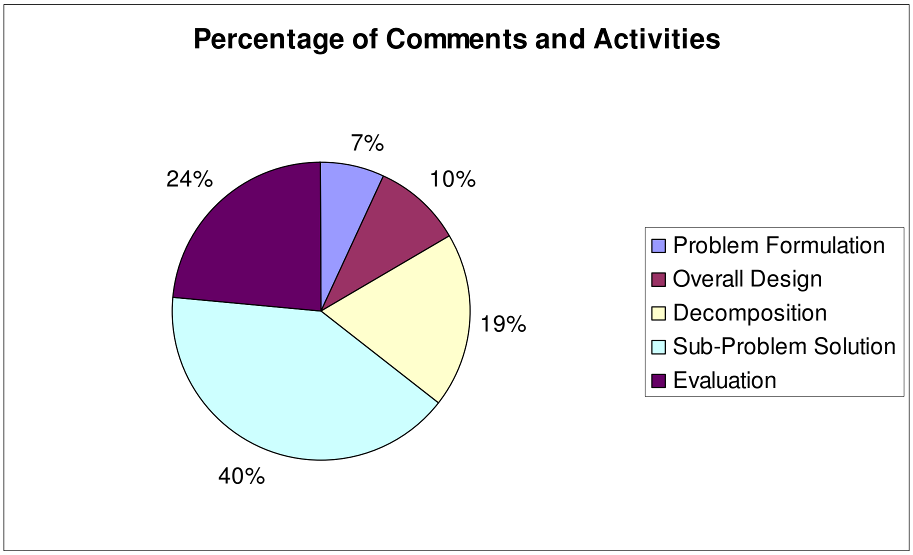
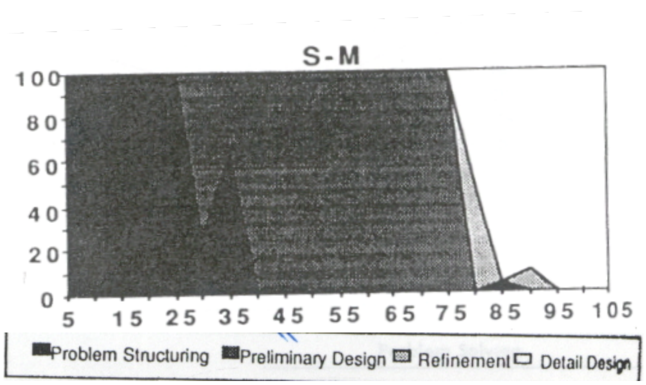


Figure 1: Percentage of Comments and Activities

The majority of the comments and activities we encoded were in the problem solving phase and included decomposition of the problem (19%), sub-problem solution (40%), and evaluation (24%). Larger problems were broken down into smaller, less complex modules. There were usually two stages to the solution of the problem. First, potential solutions would be formulated and discussed. This was usually done by the expert and team leader. Because of time, this was immediately followed by the implementation of the design idea. Materials, one of the largest constraints, usually determined whether they could follow through with the design. If the needed materials were not found, modifications to the design would be made as needed. Otherwise, the participants would get to work implementing the design. Most of the design evaluation we observed occurred once the module was built. We noticed that there seems to be several small cycles of Decomposition → Sub-Problem Solution → Evaluation interspersed in most teams' design process. We noticed that teams would tend to break the overall problem up into sub-problems, pick one (or a few) sub-problems to start with, find solutions to those few problems, evaluate those solutions, change them if needed, and then pick a few more of their sub-problems to work on next.

Comparison to Goel & Pirolli

Figure 2 shows a comparison of the Junkyard Wars design protocol to Goel & Pirolli's study of a Mechanical Engineer (1991). Both protocols started with the problem structuring or formulation stage. Unlike Goel & Pirolli's study where the participant revisited the problem structure later in the design as a way to verify he met the requirements, our data for Junkyard Wars show comments and activities in this phase only occurred during the first time period. We suspect that revisiting the problem structure was edited out of the television program.



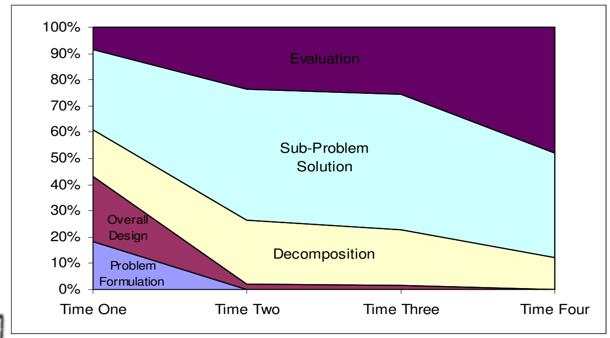


Figure 2: Comparison of Mechanical Engineering design protocol (left) to Junkyard Wars design protocol (right).

Judge's Predictions

Another element of the Junkyard Wars show is the presence of judges to evaluate the team's design during implementation and predict the competition outcome. Each episode has a guest judge who is expert in the problem domain. The judge does not interact with the participants, but can oversee their progress in their workshops. The predictions are based on the teams' overall design, the building materials they choose to use, and the detail design and implementation of the final product. The judge will make two or three predictions during the show and sometimes switch teams based on their progress. We found that in 3 out of the 6 episodes the judge's final prediction was wrong. In one case, the predicted team lost, not because of the design, but because of driver error. However, in the other two episodes, the judge's design concerns did not affect the performance of the final contraption. This raised the question - do the judges favor the design solutions that are more common or that they would choose versus a more original solution? Our study cannot answer this question, but it may be a good foundational question for a future study.

Reasons for Design Modifications

We noticed that teams would sometimes change an aspect of their design during the course of the 10-hour time period. Some reasons for these changes included available materials, the time pressure, and more refined requirements. The chosen material resulted in the need for quick design changes for one of the amphibious motorcycle teams. Their amphibi-bike consisted of a boat with a hole cut out of the hull and an old motorbike inserted into this hole. The only boat they could find in the junkyard was an old fiberglass boat with many holes in it. When trying to weld a frame on to the boat, the heat started melting the fiberglass, forcing them to continuously pour water over the boat and weld a little at a time. This took more time than they hoped, and they were unable to patch the holes in the boat as originally planned.

Host:	*The Double Deckers are running a limited service and have resorted to a quick fix of foam.*
Jason:	*I am gradually going to fill the boat up with foam as we go along.*
Host:	*Choosing a fiberglass hull certainly seemed like a good idea hours ago, but it has caused havoc with their time table.*

One design change we observed happened within minutes of the deadline with no explanation given for the decision. One participant on a hot rod team decided to add a nose to the front of the vehicle with less than 10 minutes left.

Host:	*With only minutes left, Mark has hit upon a winning idea. A really big nose.*
Dan (team member):	*That's awesome!*

We can infer this decision was made with the thought that a hot rod with a longer nose will cross the finish line before a similarly powered vehicle with a short nose. However, this was never considered in the original design or any of the sub-problem solutions. The lack of explanation of this decision may be because of the show's editing. We suspect that spontaneous decisions right before the deadline are not as well planned and are not part of the common decomposition → sub-problem solution → evaluation process. It would be interesting to do further research into this last minute decision making to understand what compels people to change the design at this time and if it is similar to other techniques such as tinkering.

One team decided to modify their design after they received more refined requirements. Right before the final challenge, each team gets an hour to tinker with and/or change their design. In one specific episode, one of the objectives of the design was to pick up a bucket. During their "tinker time", one team saw the actual bucket that their design would have to pick up. After seeing the size and shape of the bucket, the team had more refined requirements for their design. They decided to change their design so that it could better pick up the bucket and complete the objective.

Interesting Tidbits

Although we were relatively unsuccessful in finding interesting answers to our research questions, throughout our observation we did notice several interesting tidbits of information.

Due to the time constraint, the teams were forced to do a lot of satisficing. They did not have enough time or adequate materials to find the perfect solution, so they usually just found something that would work and went with that.

We also found that sometimes teams didn't focus on "the big picture". We observed one team whose design problem had three parts. The team focused intently on one part of the problem so that in the end, their device worked extremely well for that problem, but didn't work very well for the other parts of the problem. The team seemed to have become so focused on one sub-problem that they neglected the rest, and the overall design suffered for it.

Team dynamics seemed to affect the success of the final products. The teams on one episode were both military teams with strict leadership structures. One team leader admittedly had final say on any decisions, and the other two members on the team willingly obeyed. The leader had frequent “Sit-Reps”, or situation reports, to keep everyone informed of the group’s goal, the current status of each module and what was left to do. This team was successful in the competition. The team dynamics of another team caused a lot of frustration. When building the contraption, one member of this team wanted to do everything. The tasks were not evenly distributed among team members, leaving some with nothing to do. For a task such as Junkyard Wars, where time is a critical constraint, it is important for teams to utilize all their possible resources. This team was able to complete the construction of their design and ended up winning the competition. Our observations of different team dynamics and levels of frustration allow us to suggest that another element to be designed is how the team will work together. The designation of roles may affect the success of the final product.

We also observed that when team members were unsure of aspects of the design, they would discuss it with the team’s expert. Even if they disagreed, they deferred to the expert’s opinion.

> *Jim: And if you are that confident still. Then Ok, I’m no expert, we will go with [your design].*

Not only do the experts have more domain knowledge and are able to explain their reasoning, we suspect they are recalling knowledge of similar solved problems and basing their design on this.

Conclusions & Future Work

We set out to answer two questions:

- Is there one or more design processes that is usually used by the design teams on Junkyard Wars?
- Do certain elements of that design process (e.g. more time formulating the problem, more evaluation, etc.) correspond to creating a successful or unsuccessful design (in terms of winning the end challenge)?

We discovered that in response to question one, the teams that compete on Junkyard Wars appear to all use virtually the same design process. We also did not observe that winning or losing a challenge corresponded to any differences in design process. Additionally, we did not observe that failing a challenge corresponded to any differences in design process. We acknowledge that our study was highly influenced by the material that was available to us; much of the design process was cut out due to editing for television.

For future work, we think that it would be fun to actually do what we wanted to do in the first place! We think it would be extremely interesting to contact past participants of the show and do retrospective interviews. It would be even more interesting if we could gain access to the taping of the actual show and observe it first-hand.

References

Goel, V. and Pirolli P. (1992) "The Structure of Design Problem Spaces." Cognitive Science. 16, pp. 395 – 429.

Junkyard Wars Online FAQ. (n.d.) Retrieved December 10, 2003 from http://jyw.tacorp.net/faq.html

McCracken, W. M. (2003) "Research on Learning to Design Software." Chapter of some book that you probably have because you're the author.