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Systems Engineering : What You Need to Know to Build a Competitive Robot

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How do we get here?

"This is a vehicle to teach responsibility, engineering, math and science."
— DALE HALL, a TRW engineer who helped a team composed of students from Mira Costa and Redondo Union high schools

BRUCE HAZELTON/DAILY BREEZE
In a coordinated attack, the BeachBots machine, right, built by Hermosa Beach's Hope Chapel Academy, and a teammate, left, disable a robot in Saturday's contest.

VIE, ROBOTS

Students and their machines converge in Inglewood for contest's regional finals

Nonprofi
agency a
moneym
to its resu

TORRANCE: Organization
ill that closed last year after r
government funds now bring

By Josh Grossberg
DAILY BREEZE

Last summer, things looke
rance-based employment age
tally ill. Unable to secure en
funding to stay in business, En
Employment had to close its d

But instead of giving up, its
strategies. Rather than relying
port the program, Hilda Pres
go at running the nonprofit
money-making business.

"We're still a nonprofit, bu
revenue," said Prestman, who helped form the agency 19 years ago.

Find ou
mor

For starters, the agency has cemented a contract to assemble plastic medical supplies for a local company.
earn minimum wage to put the

But the larger goal is to ga
ness to hire an employment
place the mentally ill in other j

"We're doing the best we ca
Amir Nabil, who has schizop
sive-compulsive disorder, as
es together.

The agency, which operates o
off 220th Street, received fund
erative agreement between th
agencies. With a small paid st

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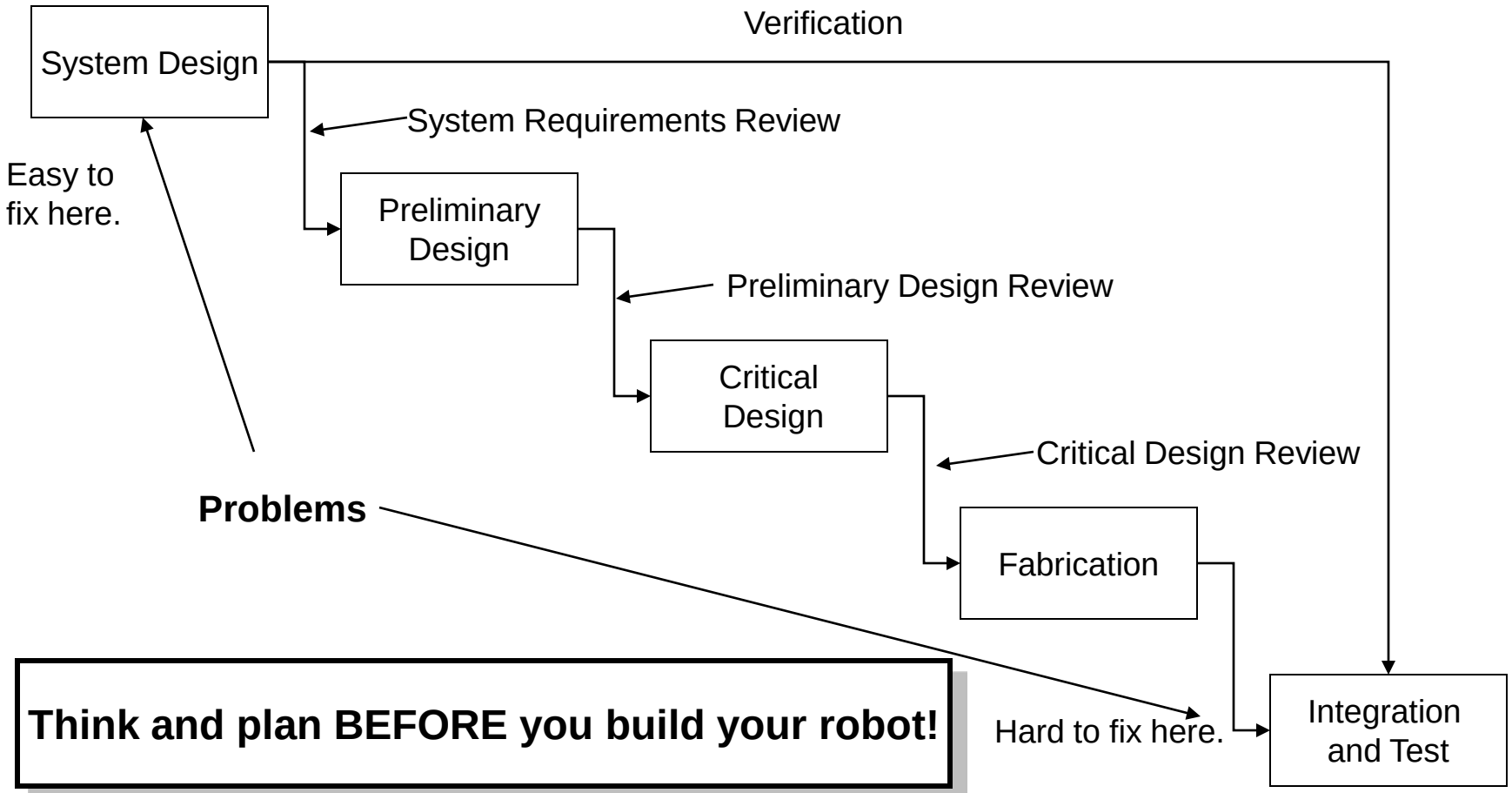
Outline

- Engineering Design Process 10 min
- Systems Engineering (SE) 15 min
- Systems Engineering Exercise 40 min
- SE Presentations 15 min
- Questions and answers 10 min

Engineering Process

Engineering Design Process: Overview



Think and plan BEFORE you build your robot!

Systems Engineering

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Systems Engineering Definition

Systems engineering is the branch of engineering concerned with the development of large and complex systems, where a system is understood to be an assembly or combination of interrelated elements or parts working together toward a common objective.

-University College London

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Systems Engineering Definition

Systems engineering is a discipline that develops and exploits structured, efficient approaches to analysis and design to solve complex engineering problems. Because systems engineering focuses on methodology rather than physical manifestations of science and engineering hardware, describing it is more difficult than for other engineering disciplines.

–Institute for Systems Research
at the University of Maryland

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Systems Engineering: "What not how"

- Understand the problem completely
  - Analyze the game
    - Read the rules
      - Read them several times
- Simulate the game
  - Walk through it
  - Use a stop watch
  - Make it realistic
  - Get everyone involved
- Brainstorm
  - Talk about what you learned
  - There are no wrong ideas
  - Every idea is important
  - Take notes –use a flipchart, use Post-Its

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Systems Engineering: "What not how"

- Understand the problem completely
  - Decompose the game
- Offense
  - How many ways are there to score
  - How many possible points are there
  - How do you get more bang for your buck
- Defense
  - How to keep others from scoring
  - How do you control your opponent
  - How do you get your opponent to score for you

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Systems Engineering

- Solve the problem
  - Game Strategy: How to win the game
    - Develop competing strategies.
    - Pick a game strategy
      - Offense
      - Defense
    - Pick a discriminator –be the best at something, be unique
  - Ask how would I beat this strategy
    - Refine your strategy
      - Identify strengths and weaknesses
      - Pick a strategy within your capabilities
  - As a team, decide on the final game strategy

- Develop a set of requirements based on this strategy
  - What does my robot have to do to play the strategy
  - Don't worry about how yet!
  - Clearly **write down** a set of requirements for your robot

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Systems Engineering: "What not how"

System Requirements Review (SRR)

- Have an SRR
  - Clearly explain the game
  - Clearly explain your strategy
    - Offense
    - Defense
  - Invite independent reviewers
    - Give them the game documentation ahead of time
    - Listen to their comments
    - **Do not be defensive**
      - You are not the only smart person in the world
      - You invited them because they are smart
      - Pride limits a lot of innovation
  - Revise your requirements based on these comments

Finding and fixing problems here is much easier and cheaper in this phase than fixing them later.

System Requirements: Example

	Requirement
1.0	Beach'bot shall comply with all rules outlined in The 2003 FIRST Robotics Competition Manual
2.0	Beach'bot shall be durable.
3.0	Beach'bot shall be stable.
3.1	Beach'bot shall be able to continue a degraded operation if custom circuits fail.
4.0	Beach'bot shall be maintainable.
4.1	All deployable mechanisms shall be retractable.
4.2	All deployable mechanisms shall be easily replaceable in 15 minutes or less.
4.3	All electronics shall be easily accessible.
4.3.1	Beach'bot shall have easy access for battery removal/installation.
4.3.2	Beach'bot shall have sufficient mounting area to co-locate circuit breakers and speed controllers/relay drivers.
4.3.3	Beach'bot shall have easy access to the 120A circuit breaker.
4.4	All electrical wires shall be color coded and labeled at both ends.
4.5	Drive motors shall be easily replaced.
4.6	All pneumatics shall be easily accessible.
4.7	All pneumatic tubing shall be color coded and labeled at both ends.
4.8	Software releases shall be documented with revision codes, dates, and change notations and stored in a portable library.
5.0	Beach'bot shall have high traction when needed.
5.1	Beach'bot shall have wheels that grip the ramp.
5.2	Beach'bot shall have wheels that grip the carpet.
5.3	Beach'bot shall have wheels that grip the platform.
5.4	Beach'bot shall have a mechanism that grips the ramp in order to stay on the platform.
5.5	Beach'bot shall not damage the carpet, ramp or platform with its wheels or mechanisms.
6.0	Beach'bot shall have a maximum speed of 9 feet per second.

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System Requirements: Example

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Systems Engineering Tools

- Modeling and Simulation
- Prototyping
- Weight tracking spread sheet
- Requirements spread sheet
- Design of experiments (DoE)
- Log books
- Brainstorming
- Analysis of Alternatives (AoA)

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Engineering Design Process: Planning Tips

- Develop a schedule
  - Work backwards from your ship date
  - Allocate enough time for System Engineering
  - Make sure you have enough time to test and drive
  - Take into account “long lead” items
    - Keep track of “long lead” items!
- Weigh everything you put on the robot!!!
  - Robots do not diet well.

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Engineering Design Process: More Tips

- Have an agenda and record minutes for all of you meetings.
- Use log books to record all of your decisions.
  - Make sure you understand why you made a decision.
- Be very systematic.
- Avoid stove piping
  - Communicate, Communicate, Communicate
- Make design documentation available for future years
  - Concurrent Version System
  - Set up a server available via the web.
  - Contact Joe Ross team 330 for details.
- Reuse proven designs where possible
  - Don’t reinvent the wheel every year

Systems Engineering Exercise

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Systems Engineering Exercise

1. Understand the problem (20 minutes)
   - Read the game
   - Analyze the game
   - Decompose the game
2. Solve the problem (20 minutes)
   - Design a game strategy
   - Develop a set of requirements
     - (What will my robot do –not how)
3. Presentations (15 minutes)

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Preliminary Design

Preliminary Design

Preliminary design is the process of transforming a set of requirements into a concept that can be implemented. It is important that the fabrication team be involved in this phase.

Preliminary Design : It's time to think about how

- Understand kit of parts completely
  - Analyze the kit
  - Check off all of the parts to make sure you got everything
  - Assign someone to weigh the parts in the kit
- Clearly understand the rules about what can be used and what cannot. (e.g. no titanium)

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Preliminary Design : It's time to think about how

- Begin to Implement the requirements
  - Divide into groups and develop competing solutions based on the requirements.
- Prototype concepts as needed
  - Formally present these to the team
  - As a team, discuss these designs
  - Look for strengths and weaknesses
  - Maximize strengths and minimize weaknesses
  - Combine the best of each into a preliminary design
  - Remember the KISS principle –simple is usually better
    - Look at past champions
      - All are innovative

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Preliminary Design : It's time to think about how

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Preliminary Design : It's time to think about how

- Divide into sub-teams
  - Drive, Manipulator, Controls, etc.
  - Allocate the requirements to the sub-teams
- Each sub-team has certain requirements to meet
- Sub-teams can develop their components concurrently
  - Systems engineering should oversee this effort
    - Make sure the functions are tied together
  - Prioritize your work to complete the most important things first. (Your drive system should be done first)
  - Keep fabrication in mind.
  - Now you're ready for critical design
- Hold many Peer Reviews
- Hold a Preliminary Design Review

Preliminary Design : It's time to think about how

- Have an Preliminary Design Review (PDR)
  - Clearly explain how your design meets the design requirements
  - Invite independent reviewers
    - Give them your requirements and your preliminary design ahead of time.
    - Listen to their comments
    - **Do not be defensive**
      - You are not the only smart person in the world
      - You invited them because they are smart
      - Pride limits a lot of innovation
  - Revise your design/requirements based on these comments

Preliminary Design: Allocated Requirements Example

	Requirement	Chassis Sub-Team	Drive Sub-Team	Lifter / Stacker Sub-Team	Wedge Sub-Team	Peacock Sub-Team	Pneumatics Team	Electrical Team	Software Team
1.0	Beach'bot shall comply with all rules outlined in The 2003 FIRST Robotics Competition Manual	P	P	P	P	P	P	P	P
2.0	Beach'bot shall be durable.	P	P	P	P	P	P	P	
3.0	Beach'bot shall be stable.	P	P	P	P	P	P	P	P
3.1	Beach'bot shall be able to continue a degraded operation if custom circuits fail.							S	P
4.0	Beach'bot shall be maintainable.								
4.1	All deployable mechanisms shall be retractable.	S	S	P	P	X	S	S	S
4.2	All deployable mechanisms shall be easily replaceable in 15 minutes or less.	S		P	P	X		S	
4.3	All electronics shall be easily accessible.	P						S	
4.3.1	Beach'bot shall have easy access for battery removal/installation.	P						S	
4.3.2	Beach'bot shall have sufficient mounting area to co-locate circuit breakers and speed controllers/relay drivers.	P						S	
4.3.3	Beach'bot shall have easy access to the 120A circuit breaker.	P						S	
4.4	All electrical wires shall be color coded and labeled at both ends.							P	
4.5	Drive motors shall be easily replaced.	S	P					S	
4.6	All pneumatics shall be easily accessible.	S					P		
4.7	All pneumatic tubing shall be color coded and labeled at both ends.						P		
4.8	Software releases shall be documented with revision codes, dates, and change notations and stored in a portable library.								P
5.0	Beach'bot shall have high traction when needed.		P		P				
5.1	Beach'bot shall have wheels that grip the ramp.		P						
5.2	Beach'bot shall have wheels that grip the carpet.		P						
5.3	Beach'bot shall have wheels that grip the platform.		P						
5.4	Beach'bot shall have a mechanism that grips the ramp in order to stay on the platform.	S	S		P		S	S	S
5.5	Beach'bot shall not damage the carpet, ramp or platform with its wheels or mechanisms.		P	P	P				
6.0	Beach'bot shall have a maximum speed of 9 feet per second.		P						S

Preliminary Design: Tools

- **Design of experiments**
- **Prototyping**
  - **FTC**
  - **VEX**
  - **Previous year's robots**
- **Computer Aided Design tools**
- **Compilers**
- **Software Simulators**
- **Labview**
- **Peer Reviews**
- **Preliminary Design Review**

Preliminary Design Exercise

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Preliminary Design Exercise

- Using the requirements developed during the Systems Engineering Exercise.
  - Break up into two teams
  - Develop two preliminary design concepts based on these requirements.

Detail Design

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Critical Design

- Detailed design is the process of refining and expanding the preliminary design of a system or component to the extent that the design is sufficiently complete to be implemented

  - Detailed CAD drawings
  - Bill of materials (BOM)
  - Weight budget
  - Cost budget
  - Time budget
  - Purchase orders

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Systems Engineering Summary

- Understand the problem before you solve it.
  - Spend enough time to understand the issues.
  - You will solve the right problem.
- If you fail to plan, plan to fail.
- Do not ignore your requirements.
  - You spent a lot of time thinking about them.
  - If you change them, do it formally.

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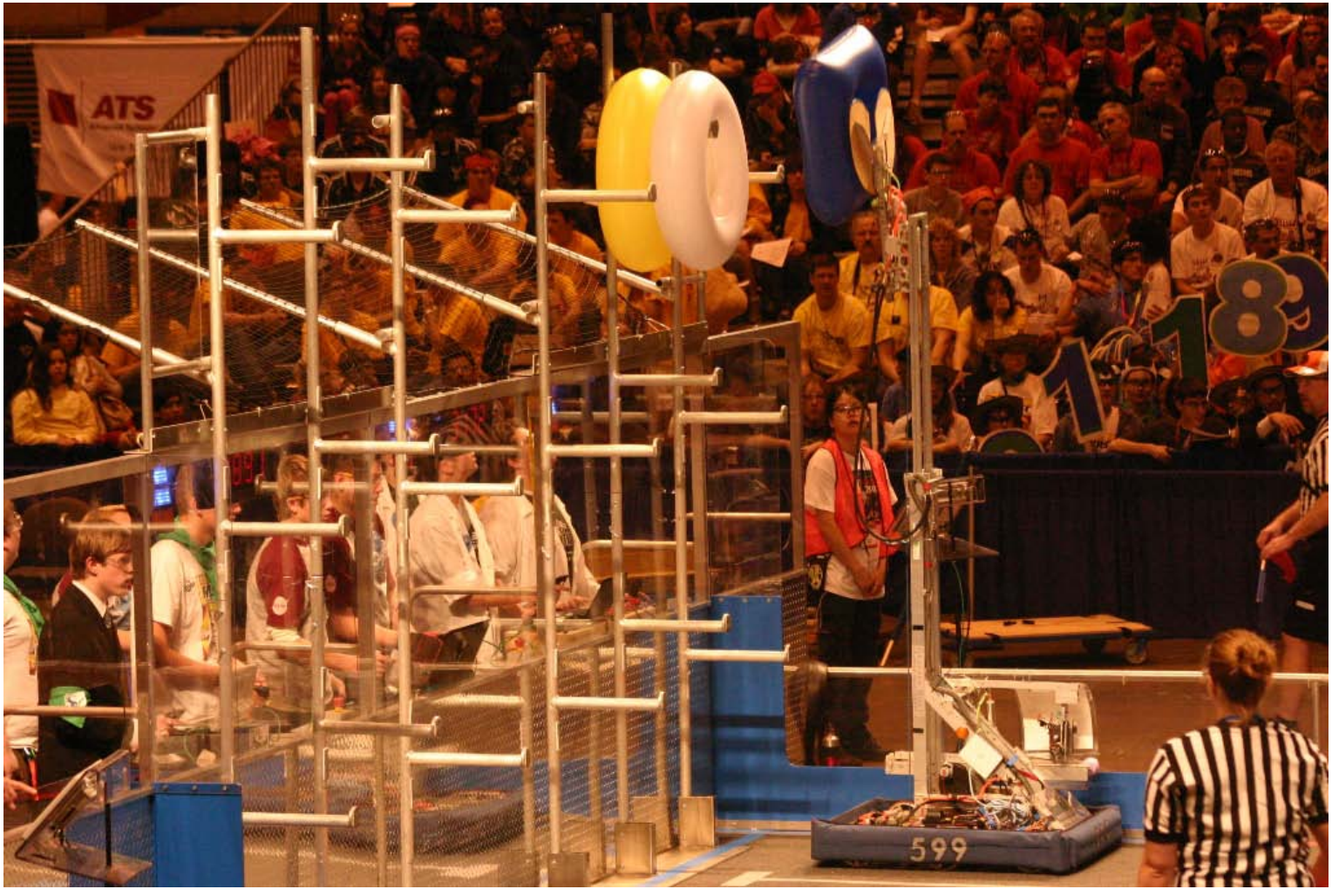
Questions and Answers



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Resources

- Freemind
  - FreeMind is a premier free mind-mapping software written in Java.
    - http://freemind.sourceforge.net/wiki/index.php/Main_Page
- GanttProject
  - GanttProject is a free and easy to use Gantt chart based project scheduling and management tool.
    - http://ganttproject.biz/