Team Jefferson 2007 DARPA Urban Challenge Debrief

Scope

The intention with recording this debriefing is an attempt to log, while fresh in memory, what we know about our team's involvement with the DARPA Urban Challenge, the things accomplished, issues encountered, and a post race assessment. A portion of the debrief is dedicated to identifying the issues that occurred so that we can understand as precisely as possible what happened and how they might be addressed for future involvement in such an event. A short summary of this debrief exists at the end of the debriefing details.

Preparation

Details related to the DARPA's announcement of the race parameters and the team's planning and advancement.

- 2006: DARPA announces Urban Challenge. Offers prize money for winners in addition to $50K for those advancing to the NQE, and $100K for those advancing to final event.
- Summer 2006: DARPA kicks-off Urban Challenge.
    - Tony Tether (DARPA director) states that prize money will not be awarded due to congress removing authority to grant money.
    - Upon examination of the referenced law, it appears that DARPA can offer prize money but has to seek prize money from its parent agency (DDR&E). It is unknown why DARPA did not directly seek prize authority from DDR&E's head John Young.
    - DARPA announces that will have Track A and Track B teams:
        - Track A teams get $1M advance funding from DARPA to compete.
- Summer 2006: DARPA rules only allow its own officials to pause and Estop vehicles. We ask DARPA if a team member from each team can also pause and estop the vehicles in parallel with the other officials. DARPA responds with a no.
- September 2006: Team Jefferson procures Scion xB and begins some work over the next few months getting the vehicle ready. Team creates three 13 month target plans relative from a start date of October 2006 until October 2007:
    - **Minimalist/Austerity** ($90K): Raise enough money for parts and some travel to the events.
    - **Winning Chance** ($400K): Raise money for parts, travel, full-time mechanical, full-time electronics engineer, three full-time software engineers.
    - **Slam Dunk** ($800K): Raise money for parts, travel, full-time project manager, full-time mechanical, full-time electronics engineer, six full-time software engineers, paid part-time consultants.
- October 2006: DARPA grants 11 $1M Track A awards. Awards granted to larger and mostly well capitalized teams (e.g. CMU with GM, Stanford with Volkswagen, Oshkosh, Honeywell/Ford, Rockwell-Collins/iRobot).
- January 2007: DARPA announces re-instatement of prize money. Does not re-instate the $50K that would go to Track B teams for advancing to the NQEs.
- February 2007: Enough money raised for initial set of parts. Hiring of full-time mechanical engineer (also assisting as electrical) to accelerate integration of permanent hardware.
- March 2007: Team has permanent actuation and basic electronics largely integrated. Effort in earnest to drop in and configure target platform software onto Scion platform starts. Basic Tommy Senior capabilities (autonomous navigation + obstacle avoidance) achieved within a week's time.
- April 2007: Team adds new rules for detecting vehicles and engaging in a passing maneuver. New e-stop system integrated. Video created to meet DARPA milestone to demonstrate such features.
- May 2007: DARPA selects Team Jefferson as one of 53 teams (out of nearly 100 applied) to receive a site visit based on video submission of capabilities.
- June 2007: More money raised for additional parts. Team procures better GPS system. Dynamic route planning, stopping at stop lines, intersection handling, tuning of passing maneuvers, 3 point U-turns, and additional fail-safe measures are added to vehicle. Flawless site visit conducted with DARPA officials watching.

- July 2007: Anticipating an NQE invitation, the teams updates its plans to raise enough cash to enter the "Winning Chance" realm (team still operating on Austerity plan budget). Team raises some money enabling student internship support for the summer. Team seeks additional money to be raised for travel and 2 full-time engineers for the next four months to focus on critical additional sensor integration tasks (stereo camera for lane/road detection + longer range and moving obstacle detection sensor integration). Beyond that, team also creates plan for use of an additional 3 full-time engineers to further increase team's chance to meet its "winning chance plan" budget goals via acceleration of navigation maneuver rules integration.
- August 2007: Team Jefferson is one of 35 teams selected to compete at the NQEs. 10 of the 11 Track A teams advance (Rockwell-Collins/iRobot team does not).
- September 2007: Team does not meet internal financial milestones for hiring full-time engineering support, but does raise enough money for additional parts and travel plans. Team relies on part-time resources to attempt integration of critical sensor tasks. Team engages full-time software resources on other critical navigation maneuvers (e.g. merging, parking, generalization of intersection handling, generalization of passing, etc).
- October 2007: Team begins trip west to NQEs. Secures a test facility in Victorville, California and leaves early to test in similar conditions one week before NQE.

Going into the event

- Road/Lane Detection:
    - Team leveraging part-time resources, achieves basic edge detection and road following but under limited circumstances. Software not complete nor tested enough for use. Still continued work at test facility.
- Route Replanning:
    - Still under development and being simulated on trip out west. Testing and bug fixing occurring at test site prior to NQEs. Successfully tested/demonstrated route replanning under a few scenarios: 1) successful replan at blocked path triggering a U-turn, 2) car comes back around to other side of blocked path and immediately triggers U-turn (recalls path blockage), 3) blockage is placed in between RNDF waypoints such that replanned points occur between RNDF waypoints. Left with little test time for integration under different scenarios.
- Low-Lying and Negative Obstacles:
    - Obstacle detection of low-lying obstacles (e.g. hay bails and curbs) and negative obstacles (e.g. ditches) not 100% tested.
- Aggressive Turn Handling:
    - Tuning for handling of sharp and/or sudden turns mostly addressed/tuned, but not fully tested.
- Speed Handling Tuning:
    - Tuning of vehicle speed control to not stop as aggressively (i.e. have smoother stops) not 100% ironed out.
- Notes on some things that <u>did</u> have ready:
    - Autonomous Steering and Speed Controls
        - Tuned/refined smooth autonomous steering and navigation.
        - Additional speed control rules for approach of special maneuvers.
        - Better/enhanced GPS positioning.
    - Route Planning
        - Handling of enhanced map features (RNDF).
        - Dynamic route planning based on mission files (MDF).
        - Basic route re-planning.
    - Lane Collision Avoidance
        - Detection of lane collisions.
        - Detecting speed of vehicles in lane and pacing TJr based on that (i.e. following).
        - Passing of cars in lane.
    - Intersection Handling and Merging
        - Stopping and queuing at intersections.

        - Detection of other vehicles at intersections and following precedence order for intersection arrival.
        - Merging at intersections with traffic, assessing ability to make turns into and across merging traffic at intersections.
    - Parking Lot Maneuvers
        - Navigating open zones in the presence of obstacles.
        - Self-parking in tight parking spots in parking lots.
    - U-Turns and Signaling
        - Maneuvering through 3-point U-turns.
        - Proper turn signaling at turns and during maneuvers.
    - Collision Avoidance
        - Basic side and rear collision avoidance.
    - GPS Outages
        - Handling of GPS outages for reasonable distances.
    - Fail-Safety and Dependability
        - Enhanced fail-safety (redundant sensing and speed control sensors, watchdog timeouts, fail-safe throttle control).
        - More robust mechanical and actuator integration.
        - More robust electronics integration.
    - Development & Test Enhancement
        - Instrumented user interface in vehicle for enhanced controls, testing, and development of vehicle rules.
        - Creation of offline simulations for enhanced development.
        - Creation of automated means for charting and creating course maps for more rapid and extensive testing.
        - Identification and use of better test facilities before and during race.
    - Operations & Marketing Enhancement
        - Extensive operational planning of team logistics to/from the event.
        - Professional planning of vehicle/trailer logos and team marketing materials (shirts, hats, etc).
        - Much enhanced team sponsorship drive and support across multiple organizations.

NQE Day 1

- During the NQE kick-off ceremony, Norm Whittaker, (DARPA program manager in charge of the Urban Challenge) discusses the lengths to which DARPA went to create the courses out of an old abandoned air force base. Amount of work was impressive.
- During the NQE kick-off ceremony, Tony Tether, (director of DARPA), indicates that safety is a number one priority and that much time and effort has been put into considering safety for the event.
- DARPA gives the team a USB stick labeled RNDF and "Team Jefferson". RNDF files are map files defining the waypoints specified by DARPA for three courses on the George AFB. Course A is a course to test merging, Course B is a long course winding through the base, and Course C is a course to test intersections. During the NQE kick-off ceremony, Tony Tether indicates that all teams will be allowed at least two attempts of each course.
- As a side note, after the DARPA Urban Challenge event, an acquaintance of the team passed on the NQE RNDF files from Tartan Racing (i.e. the Carnegie-Mellon and General Motors team). The NQE waypoints were apparently post-processed by Tartan Racing to provide better navigation for their vehicle. Subsequent graphics in this document contrast Team Jefferson's NQE waypoints given to it by DARPA with NQE waypoints used by Tartan Racing.

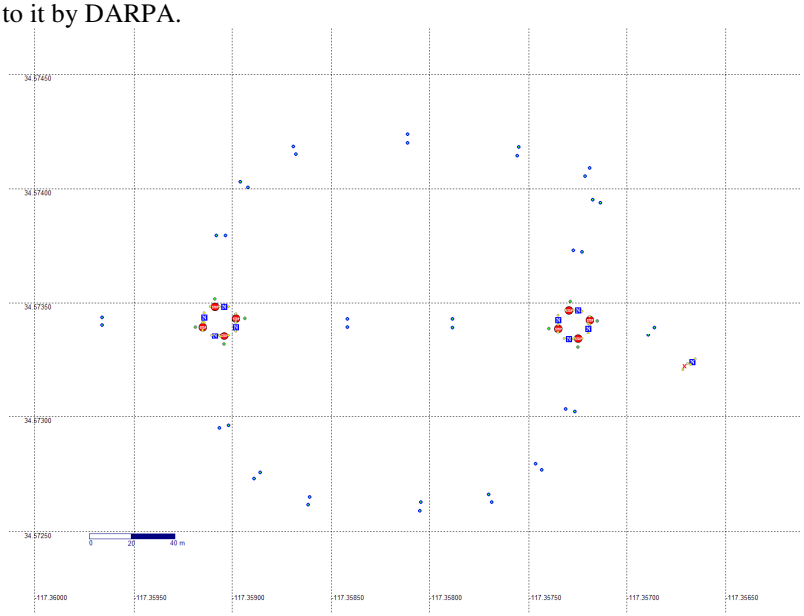
NQE Day 2

- Team called for E-stop Test: DARPA tests team's manual E-stop (Disable of vehicle), ability to remotely pause and run our vehicle, and ability to remotely disable our vehicle.

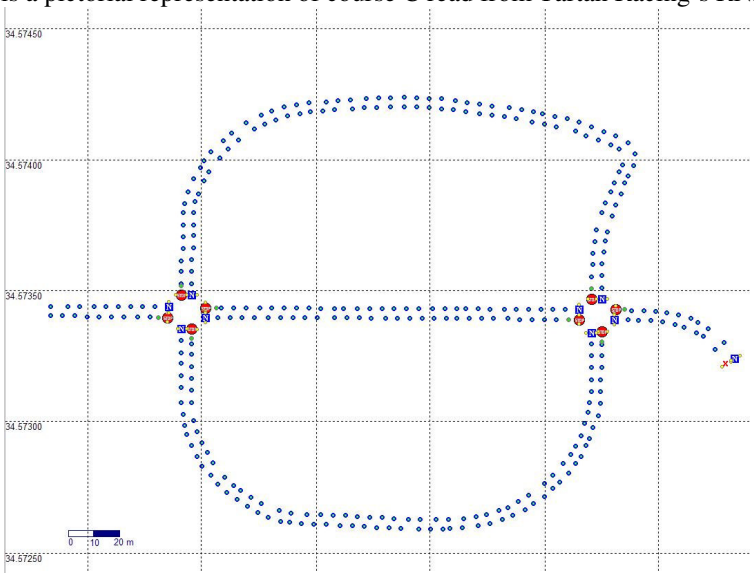
- DARPA has to re-run the test when DARPA official presses wrong button during first test (official pressed DISABLE instead of PAUSE).
- TJr successfully passes tests.

NQE Day 3

- Team scheduled for Course C: Two intersections with two loops and a road through the center. To test stopping at intersections and precedence at intersections. Also used to test blocking of a path, rerouting, and U-turns.
- The picture below is a pictorial representation of course C read from Team Jefferson's RNDF file given to it by DARPA.



The picture below is a pictorial representation of course C read from Tartan Racing's RNDF file.

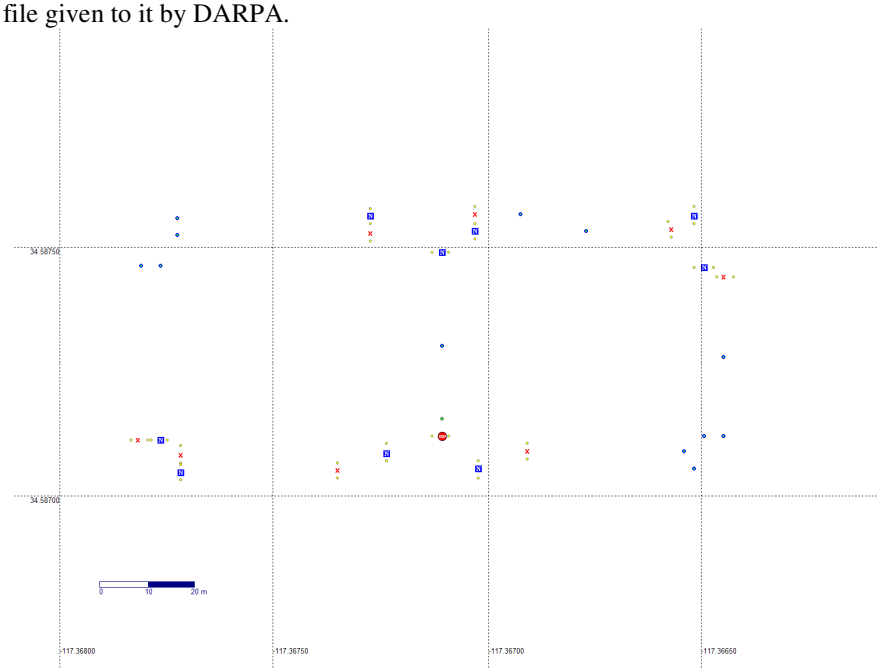


- TJr successfully stopped at intersections, obeyed precedence order, and performs the maneuvers numerous times. The mission file for this run results in planned route around outer loop 5 or 6 times.
- DARPA pauses vehicle during last loop and pulls K-barrier blockade onto track. TJr is commanded to run mode again and travels toward barrier. TJr stops and successfully detects that its route is blocked. TJr induces a replan of its route.

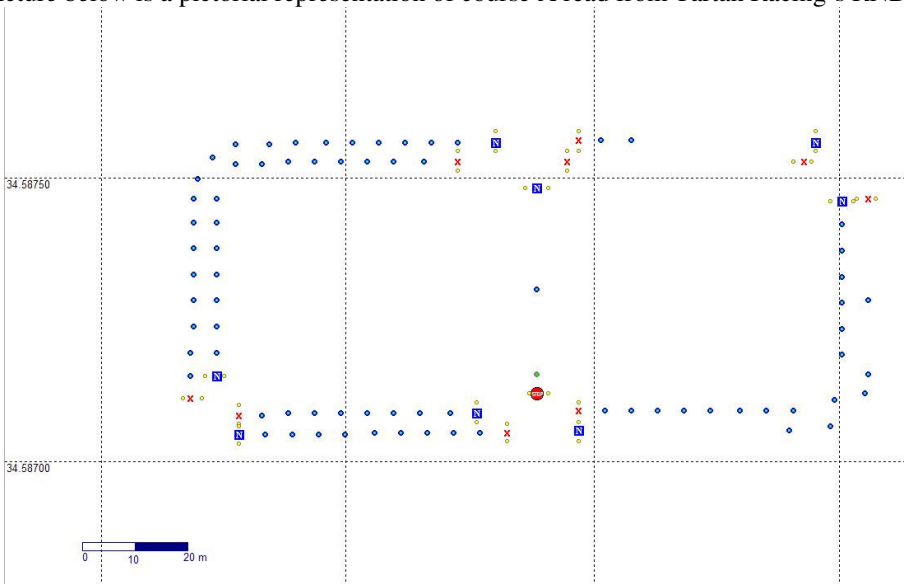
- After replan, TJr does not initiate a 3-point U-turn during reroute, but rather just navigates directly forward around replan points. This results in TJr breaching the curb during the turn.
- After replan, the lane collision avoidance handling process throws an exception. This is the process that detects obstacles on the vehicle's path.
- Vehicle replan results in vehicle traversing down center road where DARPA has placed concrete railway crossing arms that hang over the lane with no ground connection on track. TJr collides with the railway arms.
    - Issue: Non-ground based obstacles were not considered in our software rules implementation. A review of the DARPA rules indicates ground based obstacles common to city environments are the obstacles to be considered wherein obstacles hanging from the sky are not identified as candidate obstacles to consider.
    - Other teams also collide with the barrier and point out the inconsistency to DARPA. According to a few team reports, the arms themselves are apparently illegal on California roads. Also, the Stop signs placed on the arms face in the opposite direction (i.e. the dull back of the sign is visible to the driver) which further makes it difficult for laser sensors to detect the obstacle. DARPA officials positioned on the side of the crossings do not raise the crossings to avoid an impact.
    - DARPA also does not pause TJr to avoid the collision. Our logs indicate TJr was travelling at a speed of 6.5 to 7.5 mph down the center road, and that a pause signal was issued by DARPA approximately 1.5 seconds or 4 meters away from the railway arm. This is not soon enough to avoid impact.
- TJr collides with the railway arm. Its windshield is cracked and the arm is wedged beneath the vehicle's roof rack. The team decouples the arm from the rack and ends the mission. The team replaces the windshield on the vehicle that night.

NQE Day 4

- Team on Course A: A small loop with two intersections with traffic at the intersection allowing to pass through without a stop. Demonstrates intersection handling and merging with moving vehicles.
- The picture below is a pictorial representation of course A read from Team Jefferson's RNDF file given to it by DARPA.



The picture below is a pictorial representation of course A read from Tartan Racing's RNDF file.

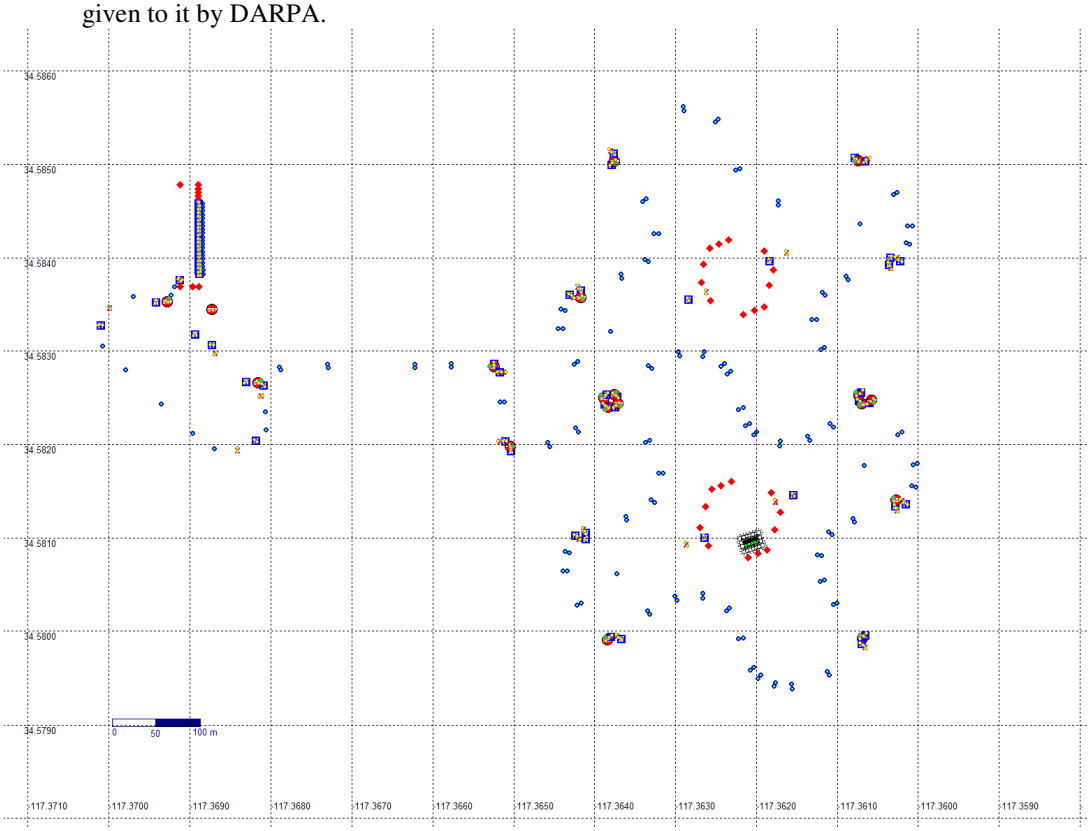


- Tjr starts out and stops at the first intersection. It seems to wait until an internal timeout triggers it to proceed.
    - Issue: The vehicle detects a portion of the ground in front of the vehicle as an obstacle. The laser mounted on front for detecting obstacles in the vehicle's lane is angled down. This is an issue remaining from the collision the prior day. The team would not discover this issue until later in the day on day 6.
- As it proceeds it properly avoids other vehicles and adjusts its speed according to the speed of vehicles in front of it.
- Tjr encounters a turn on the course and breaches the curb before it is paused.
    - Issue: A sharp 90 degree turn, coupled with RNDF waypoints provided by DARPA being partially offset, coupled with a downhill approach to the turn all combine to contribute to the vehicle breaching the curb.
- TJr is repositioned after minor adjustments by the team, but breaches the same curb again. TJr runs out of time for the course.

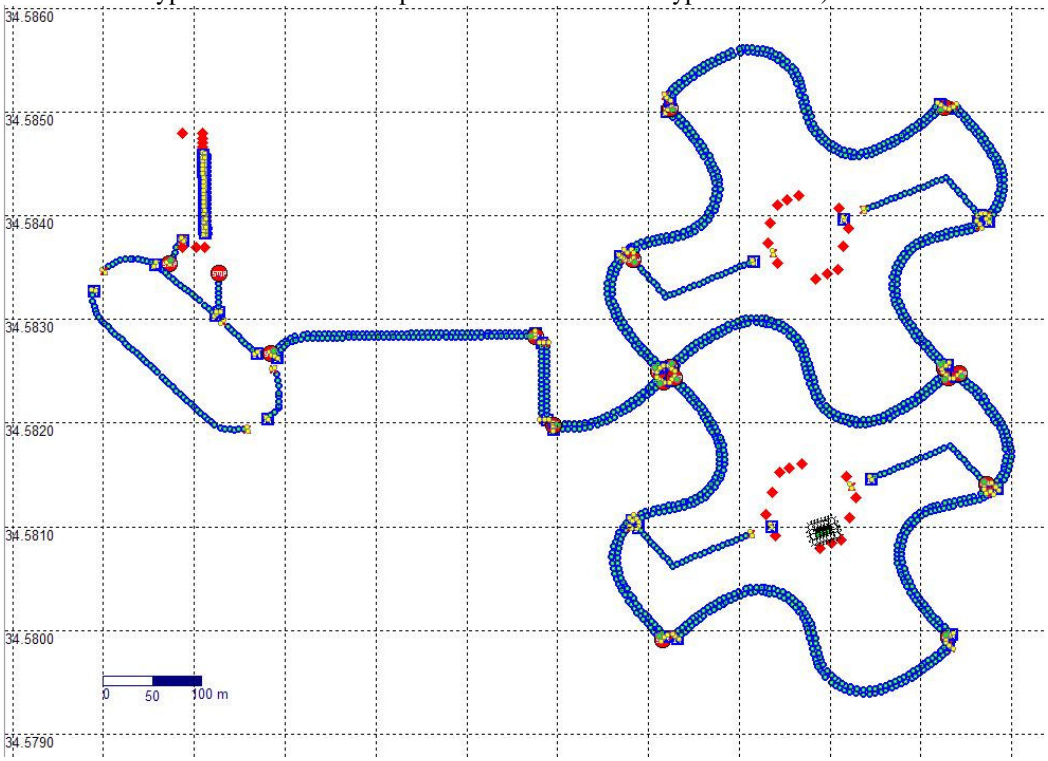
NQE Day 5

- Team on Course B: The longest course representative of a small city. A starting chute with narrow passes around a large traffic circle begin the run. Numerous intersections are strewn throughout the course along with an open zone of obstacles, a parking lot, and clover leaf turns with sparse waypoints.

- The picture below is a pictorial representation of course B read from Team Jefferson's RNDF file given to it by DARPA.



The picture below is a pictorial representation of course B read from Tartan Racing's RNDF file (illustrates large number of waypoints used to fill in sparse nature of course waypoints above).



- TJr exits from its chute smoothly and turns into the open zone. TJr traverses down the first narrow pass to the traffic circle and navigates around the circle at a decent clip.
- When exiting the large circle, TJr stops and begins considering a replan course of action as opposed to moving forward down a road lined with K-barriers on the sides.
    - Issue: The RNDF waypoints sparsely provided by DARPA seem to create a path whereby K-barriers on the side of the lane partially occlude the sides of lane.
    - TJr detects this condition as something on its lane, considers passing, but detects its passing lane occluded as well by K-barriers on the other side. A security guard standing with the team watching the vehicle mentions that during construction of the course, the construction crew was discussing how the K-barriers slightly protrude onto the road.
- The team is allowed to restart the vehicle from a position slightly past its stopped location. Two team members jump into a chase vehicle and reposition TJr slightly down the lane lined with K-barriers.
- Upon restarting TJr seems to detect another impasse and begins considering a replan. The team members in the chase vehicle ask the DARPA officials in the car to communicate a pause request. TJr initiates a turn and bumps into a K-barrier.
    - Issue: TJr detected that it was on the left lane as opposed to the right lane on which we restarted the vehicle. The RNDF waypoints offset provided by DARPA lead to this issue.
    - A 3-point U-turn is not triggered and the vehicle instead conducts a forward U-turn.
    - A member from another team standing with our team indicates that the chase vehicle driver was adjusting his seat belt as a pause command was being requested.
- The team inspects the vehicle and notices damage to the lowest mounted laser. We reposition the vehicle for another start on the course. This time, we restart the vehicle closer to the right side of the lane and observe that it is now detecting that it is in the right lane.
- TJr proceeds down the path of K-barriers, stops and makes a right turn at a stop sign. TJr proceeds further down the course before time runs out and the vehicle is stopped.

NQE Day 6 (morning)

- Course C again.
- The team worked into the night prior to today's re-run of course C attempting to address the primary and most risky issue from the first run of course C, which was the low hanging obstacle. The team mounts another laser high onto the vehicle with a vertical beam to detect discrete obstacles in front of the vehicle, be they ground based or not. After some testing later that night at our test location, the team feels that it can detect the low hanging obstacles in front of the vehicle.
- Upon returning to the track, the team discovers that DARPA has removed the low hanging railway arm obstacles from the course.
- TJr also experiences an unusual GPS outage before entering the course. The team learns that a few other teams also experienced an outage at the same location that same day and there are reports in the media about it as well. The team repositions TJr away from the area to reacquire its GPS signal. When called to enter the track for its run, the team scurries TJr quickly past the area where the outage occurred.
- TJr begins its runs and seems to be operating correctly. At the far loop after passing through the intersection, the vehicle stops and begins to consider a replan.
    - Issue: One of two scenarios occurred here. TJr's lower laser detected a portion of the ground (it was still angled down after the bump with the wall on course B), or the newly added upper laser for detecting low hanging obstacles picked up a portion of the ground farther ahead.
- After repositioning the vehicle, it initiates another replan and breaches the curb significantly whereby the vehicle is paused.
    - Issue: A 3-point U-turn after the replan is not triggered and the vehicle instead conducts a forward U-turn.
- Upon repositioning the vehicle, time runs out for course operations.

NQE Day 6 (afternoon-evening)

- After its second attempt at course C, the team takes the vehicle to its off site testing location to prepare for the next day's scheduled runs. The team is scheduled to complete their second run of Course A and Course B the next day.
- The team focuses on addressing concerns for Course A first. The first issue noticed at this point was that the laser mounted in front of the vehicle for lane collision avoidance is pointing downwards a few degrees. Subtle enough to not notice immediately, but upon running the vehicle at our test location and a visual inspection it was apparent. The only hypothesis is that this was a result of the collisions on course B and/or course C on prior days. A quick adjustment of the laser angle fixed the issue.
- We also examine the geometry of course A and perform a few configuration changes to enable the vehicle to more aggressively handle the curve. We test a similar geometry of course A at our test location both before and after the configuration changes and address the issue.
- While still preparing for the next day's scheduled runs of course A and B, we get a call from the DARPA official running course A asking if we'd like to come run course A now versus tomorrow. He states that Tony Tether is there at course A watching the vehicles. That's all the information conveyed. We ask if it is mandatory or if it is optional and he tells us that he doesn't know.
- While we think that we've licked course A's issues, we still wanted to test the configuration changes as Mike Woosley begins trying to inquire with DARPA officials as to whether or not its mandatory that we run course A today or if we can take our scheduled second attempt at course A and course B the next day. We also harkened back to the 2005 DARPA Grand Challenge whereby we hastily re-ran our last run of the NQE course in response to DARPA official requests instead of taking an extra hour to calibrate the steering and the result was not positive.
- As Mike was making calls, Tony Tether calls Paul Perrone and a rough paraphrase of the conversation ensues:
    - Tony: Hello Don?
    - Paul: This is Paul
    - Tony: Looking for Don the team lead of Team Jefferson
    - Paul: This is Paul Perrone. I'm team lead for Team Jefferson
    - Tony: I'm calling to let you know that you guys are out. You're not going to make it.
    - Paul: We were just called and asked to re-run course A, that you were there watching, and we were calling around to see if it was mandatory or not.
    - Tony: It's not going to matter. I need to make time for other teams to take some runs.
    - Paul: It was our understanding that you asked us to run course A again, so why would we be allowed to re-run our second run at course A if we were out.
    - Tony: That's because I didn't get around to you in time.
    - Paul: I disagree with the decision. And I'd like to confer with my team and come speak with you about this.
    - Tony: Good luck trying to find me. (hangs up)
- Tony Tether's conversation was impolite given the circumstances. This then left our team trying to assess what could be done. Mike Woosley and George Cahen attempted to track down Tony and Norm Whittaker to discuss. Norm tells Mike Woosley to send Tony an email with an appeal and that we'd find something out tonight. For some reason, we think 10pm is the deadline. The team continues working on the vehicle into the night and still no word is received.

NQE Day 7

- The next morning, the team shows up early. Mike hasn't received a response from Tony and the team sees its name on a list of teams that are eliminated. After Janie goes to the information tent requesting that the team be able to have a conversation with Norm Whittaker or Tony Tether, a DARPA representative shows up at the team pit area with Norm Whittaker.
- The team explains its situation and desire to take its schedule runs. Paul explains to Norm that there is a communications issue. That the team was told they'd have two scheduled runs per course, that they were not told if the early call to re-run course A was mandatory or not, and that they still hadn't heard from Tony Tether regarding the team's query to this effect. Norm explains

that he understands and that he and other DARPA officials are finding out from the teams who is in or out. All eyes point to Tony Tether as the sole decision maker regarding which teams are in or out with no explanation or exposure to the decision making process.

- Norm asks if we'd like to go speak to Tony and we say yes. He takes us over to course A where Tony is standing judging the teams running the course. Tony is apparently flagging teams as in or out on the spot.
- We get a minute of Tony's time. Mike asks if he's read our appeal and Tony says no. We explain to Tony our situation and he says that we're out and that he won't reverse his decision. His explanation is that he has to make time for other teams. We ask him to reconsider, explain that we've spent a lot of time and energy to get to this point, travelled across country to compete, and would like to take our last two scheduled 30 minute runs. Tony says no, and we leave.
- We learn that there are other teams in the same boat. That they're being rushed through runs, flagged as out or to rush over to the next run.
- We also learn that some courses are idle with no teams lined up but with officials standing by.
- We learn that on the day we were asked to run our second run of Course A early, that Stanford didn't do so well on its second run of the same course and were permitted to perform a third run of the course that same day.
- We learn that a few other teams including Track A teams like TerraMax and Golem had collisions and safety hiccups.
- A few of our team are told by a media representative covering the race that they thought the reason for accelerating the NQE schedule was because Tony Tether had to leave early for another event.

Final Event Announcement

- 11 teams are selected by Tony to advance to the finals. This was posted on Carnegie Mellon's Web Site:
    - The issue of safety was brought home to Tether late in the just-concluded National Qualification Event. He was in a vehicle that was following a vehicle as it made its way through the winding roads of Test Area B. Suddenly, the vehicle did a U-turn and headed directly at Tether's vehicle. "Five of us in the vehicle were all yelling 'pause!'" Tether recalled, referring to the pause command that DARPA could send to a vehicle. A safety driver did hit the pause button and the vehicle came to a screeching halt about four feet from the front bumper of Tether's vehicle. "That reminded me that this is not a game," he said. "That tempered, quite frankly, how many (teams) are getting in."
- 7 of the 11 teams are Track A teams (of 11 Track As):
    - Tartan Racing (CMU and GM)
    - Stanford (Stanford University and Volkswagen)
    - Victor Tango (Virginia Tech, CAT, and Ford)
    - Intelligent Vehicle Systems (Honeywell, Ford, Delphi)
    - Oshkosh Trucking Company
    - MIT
    - Cornell
- 4 other teams are Track B teams:
    - Ben Franklin Racing (UPenn and Lehigh)
    - Annieway (German group of universities and industry)
    - CarOLO (German industry group)
    - UCF (University of Central Florida)

Time and Money Breakdown

Team Jefferson Targeted Urban Challenge Cost and Time Estimates (Oct 2006 to Oct 2007):

- Minimalist/Austerity Plan ($90K): Parts, travel.
- Winning Chance Plan ($400K): Parts, travel, F/T mech, F/T electronics, 3 F/T software.
- Slam Dunk Plan ($800K): Parts, travel, F/T mgt, F/T mech, F/T electronics, 6 F/T software, P/T consultants.

Team Jefferson Actual Urban Challenge Cost and Time Estimates (starting in earnest Feb 2007 to Oct 2007):

Estimated Costs	
Equipment (car, sensors, hardware, etc)	$47,000
Facilities (gas, tools, ops, etc)	$11,000
Advertisement (logos, shirts, etc)	$5,000
Travel (NQEs, site visit)	$44,000
Non-Labor Cost	*$107,000*

Estimated Time	*Man-Months*	*Man-Years*
Operations	3.26	0.27
Software	10.41	0.87
Mechanical/Electrical	13.86	1.16
Total Time	*27.54*	2.30

Other Team Example Cost and Time Estimates:

- 11 Track A Teams received $1M from DARPA to compete.
- CMU linked with GM: track A, millions spent, 50+ team members, 100s man-years
- Stanford linked with Volkswagen: track A, Stanford, VW, Google, Red Bull dollars
- Victor Tango: track A, Va Tech, CAT, Ford dollars

Summary

Team Jefferson's 2007 DARPA Urban Challenge effort began addressing the shortcomings identified from the team's 2005 DARPA Grand Challenge experience. This included lack of up-front and full-time support for mechanical and electrical engineering. The team addressed such issues this challenge by engaging full-time mechanical and electrical support up front, albeit behind the team's initially planned schedule. The team also raised enough money to buy equipment and fund travel reasonably well in advance of the anticipated need. Finally, the team also addressed many fail-safe features deemed desirable before releasing their bot Tommy Junior into DARPA's safety control.

While the team met the 2007 DARPA Urban Challenge head on addressing concerns from the 2005 DARPA Grand Challenge, the Urban Challenge was an order of magnitude more complex than the 2005 DARPA Grand Challenge. The team understood this entering the challenge and created three plans: 1) an austerity plan of $90K funding for parts and travel; 2) a 'winning chance' plan of $400K for parts, travel, and 5 F/T engineers; and 3) a 'slam dunk' plan of $800K fully funding the team's parts, travel, 8 F/T engineers, and P/T operations and consulting needs. Ultimately, approximately $47K was applied toward parts and over $40K was applied toward travel. Labor was largely unfunded but included 2.3 man-years of labor total, of which 10 man-months were spent on software.

The team's primary technical shortcomings entering the race were in an incomplete road and lane detection solution, untested route re-planning, untested low-lying obstacle detection, and non fully tuned turn and speed handling. While the team attempted to address these shortcomings toward the tail end of the project with part-time and over-time labor support, the desired full-time support on such tasks was not achievable at the level of funding and time remaining. Rather, much time was spent on successfully addressing many

other critical tasks. The team did produce, in only a year's time, enhanced autonomous steering and speed controls, route planning, lane collision avoidance, moving car following, vehicle passing, intersection handling, merging, parking lot maneuvers, 3-point U-turns, proper turn signaling, dynamic collision avoidance, GPS outage handling, fail-safety and dependability features, development & test enhancements, and operations & marketing enhancements.

Over 100 teams initially applied for participation, only 53 teams were granted site visits (which Team Jefferson aced), and only 35 teams were invited to the national qualification events in California (of which Team Jefferson was one). In the end, DARPA only selected 11 teams to advance to the final event of the 35 invited to the national qualifier events. Of the 11 teams, 7 were Track A teams with $1M advance funding from DARPA. Team Jefferson (and other national qualifiers) were not granted their two scheduled runs per course (6 runs total) during the national qualification events. What's more, involvement in this challenge's event yielded more insight into the decision making process of DARPA's conduct of grand challenge operations. This challenge's events point to an exclusive body of decision making being wielded by the Chief Judge and DARPA director, Tony Tether. What's more, it's apparent that many rules of engagement were being made on the fly by the Chief Judge at the event itself. The discretionary and last minute decision making on the part of the Chief Judge raised the bar even further for under-capitalized teams like Team Jefferson who relied heavily on rules published by DARPA prior to the race and who designed for race conditions rather than for generalized or unforeseeable conditions.

The issue with designing according to published rules versus generalized conditions was further highlighted when Team Jefferson impacted a low hanging railway crossing arm during one of its runs. DARPA's published city driving challenge rules allude only to ground based obstacles, and California laws prohibit such an obstacle class on California city roads, hence not being something to consider for the race. While many teams had similar issues with the concrete railway crossing arm's obstacle's placement, Team Jefferson's impact led to subtle issues that hampered Tommy Junior's performance during subsequent runs. Finally, while DARPA requires sole control of the safe shutdown of the team's bot during runs, on more than one occasion, DARPA did not safely stop the team's bot (nor did they stop other team's bots) responsively enough before impact. DARPA does not allow the teams to safely shut their bots down in parallel to officials.

In summary, the team was up against two major challenges during its efforts. The first challenge was time and money. Raising enough money up front to surpass a 'winning chance' prior to involvement is key. Only with such up front capitalization can the team best advance past critical task completion earlier, but also to address more generalized race conditions not explicitly defined by DARPA up front. Furthermore, DARPA's safety procedures have repeatedly demonstrated their difficulty with guaranteeing the safety of the team's primary asset, their robotic vehicle, during the competitions. Thus, unless DARPA will allow a member of each team to safely pause and stop their vehicle in parallel with DARPA officials, more time and money would need to be spent focusing on the design for conditions enabling the vehicle to safely shut itself down before DARPA officials. Regardless, if involved, the team would again petition DARPA to allow team members to also have E-stop control of their vehicles.

The second challenge is getting past the arbitrary and capricious decision making by the Chief Judge that is inherent to the DARPA challenges. While more well defined rules would enable better planning on the part of the teams, after involvement in both 2005 and 2007 DARPA challenges, additional insight provided directly from DARPA personnel as well as from other teams, it is apparent that advancement to the DARPA challenge final events are decisions made almost exclusively by the Chief Judge under wavering conditions. This is opposed to decisions being made by the organization of DARPA and grand challenge program managers, and under well-defined and pre-published selection criteria. Lacking an organizational change to the DARPA grand challenge programs, it is apparent that teams enter the event under conditions involving arbitrary and capricious decision making. Thus, in order to compete in the DARPA run challenges, a team must raise enough money to put it into a 'slam dunk realm fairly early in the game and consider a wide range of generalized conditions as part of its final design. Otherwise, teams enter an event whereby random and last minute decision making by the Chief Judge renders the team's time and money spent, as well as tax payer money spent, wasted and mismanaged.