CHAPTER I. INTRODUCTION

The Defense Advanced Research Projects Agency (DARPA) established the Grand Challenge to “promote innovative technical approaches that will enable the autonomous operation of unmanned ground combat vehicles.” ([1] and [2], p. 4). DARPA described the Grand Challenge as a race during which autonomous vehicles would be required to “navigate from point to point in an intelligent manner so as to avoid or accommodate obstacles and other impediments to the completion of their missions.” ([1]) or, worded slightly differently, to “navigate from point to point in an intelligent manner to avoid or accommodate obstacles including nearby vehicles and other impediments.” ([2], p. 4).

No challenge vehicle successfully completed the 2004 Grand Challenge Event (GCE).

Following the 2004 GCE, DARPA reported ([3], pp. 1 - 2)[1]:

> **Rationale for Using Congressional Prize Authority for Autonomous Ground Vehicle Development**
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> Following a series of studies, and influenced by a Congressional directive[1], DARPA determined that the first use of the Congressional prize authority would be in the area of autonomous ground vehicles with the following goals:
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> - Increase the number of performers working on autonomous ground vehicle technologies.
> - Provide DoD access to new talent, new ideas, and

innovative technologies by motivating and enlisting innovators that would not normally work on a DoD problem.

- Accelerate autonomous ground vehicle technology development in the United States in the areas of sensors, navigation, control algorithms, vehicle systems, and systems integration.

1 Congress expressed a clear interest in accelerating unmanned vehicle capabilities and, in fact, set a goal for the Department of Defense: The Fiscal Year 2001 National Defense Authorization Act states, "It shall be the goal of the Armed Forces to achieve the fielding of unmanned remotely controlled technology such that...by 2015, one-third of the operational ground combat vehicles of the Armed Forces are unmanned." Given the aggressive timeline in the directive, DARPA determined that organizing a prize authority event would be the quickest and most cost-effective approach to stimulate innovation and expand the research community in autonomous ground vehicle technologies.

Based on the results of the 2004 GCE, DARPA held a second Grand Challenge in 2005. On October 8, 2005, four teams participating in the 2005 GCE successfully completed the course. A fifth team completed the course the next day. DARPA awarded the prize of $2 million to Team 2005-16, the first team to complete the course.

The successful completion of the 2005 GCE was widely considered to be a significant achievement. DARPA stated: "The results prove conclusively that autonomous ground vehicles can travel long distances over difficult terrain at militarily relevant rates of speed." ([5]).

However, the actual goal of the Grand Challenge was concealed by the format of the Grand Challenge as a race. As noted by DARPA[1], the Fiscal Year 2001 National Defense Authorization Act states: "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that...by 2015, one-third of the operational ground combat vehicles are unmanned." ([4], p. 46).

DARPA published rules prior to the 2004 and 2005 GCE. The rules reported a problem statement which was revised continuously prior to the 2004 GCE, through the 2004 GCE itself, to successful completion of the 2005 GCE. DARPA published clarifications to the rules, but also revised course length, maximum corrected time, and expectation of obstacle avoidance:

- DARPA revised the maximum corrected time of the 2004 GCE from greater than 10 hours to 10 hours on April 1, 2003, several weeks after the official start of the 2004 GCE on February 22, 2003.
- DARPA revised the proposed 2004 GCE course length continuously from the official start of the 2004 GCE on February 22, 2003 through the publication of revision "5 January 2004" of the 2004 GCE rules on January 5, 2004 from 300 miles to less than 210. The reported 2004 GCE course length was 142 miles.
- DARPA stated the 2005 GCE course length would not exceed 175 miles. The reported 2005 GCE course length was 131.6 miles.
- Prior to the 2004 QID or GCE, DARPA stated: "DARPA intends to clear the

Challenge Route of non-Challenge traffic and obstacles, but can not guarantee that there will be no non-Challenge traffic, obstacles, or humans on the Challenge Route... Sensing and processing designs must be able to avoid collisions with any obstacle, moving or static, that may exist on the route." ([1] and [6]). As a result, DARPA established an expectation that teams participating in the 2004 GCE would not encounter obstacles deliberately placed on the 2004 GCE course by DARPA to test and evaluate challenge vehicle obstacle detection and avoidance.

- Prior to the 2005 GCE, DARPA stated: "The vehicle must avoid collisions with any obstacle, moving or static, on the route. DARPA will place obstacles along the route to test obstacle avoidance capabilities." ([2], p. 22). DARPA later stated: "...vehicles were required to detect and avoid obstacles along the route..." ([7], p. 4) and "The 132-mile route contained a series of graduated challenges beginning with a dry lake bed, narrow cattle guard gates, narrow roads, tight turns, highway and railroad underpasses... Vehicles passed through tunnels and avoided more than 50 utility poles situated along the edge of the road." ([7], p. 9). Although both of these claims are true, DARPA did not report obstacles were placed along the route "to test obstacle avoidance capabilities".
- DARPA placed obstacles on both the 2004 Qualification, Inspection, and Demonstration (QID) and 2005 National Qualification Event (NQE) courses to evaluate challenge vehicle obstacle detection and avoidance capabilities.

In addition, a detailed course analysis indicates course difficulty changed between

2004 and 2005. For various reasons, the 2005 GCE course was not as difficult as the 2004 GCE course. For example:

- The 2005 GCE course was located on terrain with much less slope overall than the 2004 GCE course.
- The 2005 GCE RDDF eliminated extreme lateral boundary offset and course segment lengths similar to those defined by the 2004 GCE RDDF.
- The length of the 2005 GCE course was 131.6 miles, less than the 142-mile length of the 2004 GCE course. The maximum corrected time was not reduced to ensure an "average minimum speed of approximately 15 - 20 mph" ([3], p. 2) was achieved for either event.
- The 2005 GCE RDDF defined more waypoints than the 2004 GCE RDDF. As a result of this increase and the decrease in length of the 2005 GCE course compared to the 2004 GCE course the average distance between adjacent waypoints decreased and waypoint density increased.
- The 2005 GCE course was, overall, "smoother" than the 2004 GCE course. As a result of the increase in waypoint density, the 2005 GCE RDDF required more changes in bearing than the 2004 GCE RDDF, but these changes in bearing were less severe than those required by the 2004 GCE RDDF.
- The 2005 GCE RDDF defined forced deceleration lanes before significant terrain features.

In summary, the evidence supports a conclusion that the 2005 GCE course was engineered and “groomed” to reduce its difficulty and increase the opportunity that at least one challenge vehicle would successfully complete the course.

The problem statement reported by DARPA was ostensibly one of autonomous navigation. Teams which participated in the 2004 and 2005 GCE were required to develop an autonomous vehicle with a controlling intelligence able to:

- distinguish the course from terrain that was unnavigable or was declared off-limits[2] based on detailed course information withheld until two hours prior to the event, and which identified the course and established speed limits which the controlling intelligence was required to observe, and
- navigate the course identified, while
- detecting and avoiding unintended obstacles encountered on the course,
- in less than ten hours at an average speed greater than 15 mph.

To “win”, teams were required to develop the autonomous vehicle which completed the course in the least “maximum corrected time”.

These problems were, to various degrees, solved prior to the Grand Challenge. As a result, based on a comprehensive review of published records, the author concluded the problem statement reported by DARPA concealed the fundamental problem of the Grand Challenge (“fundamental problem”), which was *system integration:*

- The Grand Challenge required teams to integrate sensor data intelligently, and integrate computer hardware with various sensors and the research platform on which they are mounted. Some teams which focused on the fundamental problem were *potentially disruptive*.

- The vast majority of failures during the 2004 and 2005 GCE were not failures of artificial intelligence, but system integration failures.

The Grand Challenge was therefore more a test of successful system integration than successful artificial intelligence, and the conditions of the Grand Challenge favored teams with greater experience and sponsorship.

As a result, in the broader context it is important to place the Grand Challenge in perspective, and determine what, exactly, the successful teams achieved in 2005.

In general, teams which participated in the Grand Challenge described the technical details and information concerning their approach to solving the fundamental problem in published records. Some team solutions demonstrate technical achievement in system integration. Analysis indicates that most teams spent a significant amount of money on their solutions to the problem, and that the total cost of team solutions represents an investment which exceeds what the Department of Defense may reasonably be expected to pay to procure them.

In addition, team challenge vehicles were mindless automatons incapable of true autonomous navigation, although some team challenge vehicles were capable of autonomous obstacle detection and avoidance and path detection while following a "bread crumb" trail.

As a result, team solutions were impractical solutions to the problem of autonomous navigation.

Although DARPA reported the Grand Challenge proved "...conclusively that autonomous ground vehicles can travel long distances over difficult terrain at militarily relevant rates of speed." ([5]), significant progress toward the goal of the Department of Defense to have one-third of operational ground combat vehicles unmanned by 2015 has not been made in the years since the 2005 GCE.

The author gained a greater appreciation for the difficulty teams participating in the 2004 and 2005 GCE must have faced while completing this research. However, the perspective of this research is that the Grand Challenge was a failure, despite the fact that prize money was awarded by DARPA, for the following reasons:

- the technical achievement was consistent with the state of the art,
- the development of basic algorithms and strategies for control of an autonomous vehicle was not the focus of the Grand Challenge,
- the cost of proposed solutions far exceeds what the Department of Defense may reasonably be expected to pay to procure them, and
- DARPA failed to structure the Grand Challenge to ensure long-term realization of its stated goals, and
- significant progress toward the actual goal has not been made in the years since the 2005 GCE.

The author asserts the use of simulation as a complement to the Grand Challenge would have provided teams participating in the Grand Challenge with a way to identify key factors contributing to success prior to field trials, increased focus on the development of basic strategies and algorithms to enhance the intelligence of autonomous vehicles, and provided a way to increase the competitiveness of the Grand Challenge by “leveling the playing field”, allowing teams with less experience or sponsorship to compete on a more even basis with teams with significant experience or sponsorship.