Table III. Team reference numbers.		
Team name[39]	**2004**	**2005**
A. I. Motorvators	01	
Axion Racing	02	01
The Blue Team	03	
Center for Intelligent Machines and Robotics (CIMAR)	04	02
CyberRider	05	
Digital Audio Drive (Team DAD)	06	03
Desert Buckeyes		04
The Golem Group (2004) / The Golem Group/UCLA (2005)	07	05
The Gray Team[a]		06
Insight Racing	08	07
Intelligent Vehicle Safety Systems I		08
Mitre Meteorites		09
Mojavaton		10
MonsterMoto		11
Princeton University		12
Palos Verdes High School Warriors	09	
Red Team	10	13
Red Team Too		14
Rob Meyer Productions	11	
Rover Systems	12	
SciAutonics I (2004) / SciAutonics/Auburn Engineering (2005)	13	15
SciAutonics II	14	
Stanford Racing Team		16
Team Arctic Tortoise	15	
Team Cajunbot	16	17
Team Caltech	17	18
Team Cornell		19
Team ENSCO	18	20
Team LoGHIQ	19	

Team Overbot	20	
Team Phantasm	21	
Team Spirit of Las Vegas	22	
Team TerraMax	23	21
Terra Engineering	24	
Virginia Tech (2004) / Virginia Tech Grand Challenge Team (2005)	25	22
Virginia Tech Team Rocky		23

Note:

[a] The title of the technical proposal hosted by the Archived Grand Challenge 2005 website ([19]) is “GreyTeam.pdf”. All other references, including the Team 2005-06 technical proposal, are to “Gray Team” or “Team Gray”. The team's preferred spelling is used herein.

Table IV. "Drop dead time".						
Waypoint	Distance to waypoint, miles (ideal)		Time to waypoint, HH:MM:SS (ideal)		"Drop dead time", HH:MM:SS	
	Completed	Remaining	Elapsed	Remaining	Time	Remaining
732	33.871	108.422	1:50:24	8:09:36	13:30:00	3:00:00
946	53.881	88.412	2:46:12	7:13:48	14:15:00	2:15:00
1627	82.099	60.194	3:56:24	6:03:36	15:30:00	1:00:00
2024	109.036	33.257	4:58:12	5:01:48	16:30:00	0:00:00

Table V. Adopted and derived geometric constants for major coordinate systems.			
Coordinate system	a	b	1/f
WGS84	6 378 137	6 356 752 . 314 2	298 . 257 223 563
GRS80	6 378 137	6 356 752 . 314 140	298 . 257 222 101
WGRS80/84	6 378 137	6 356 752 . 3	298 . 26

Table VI. Course length.		
Year	Calculated length, miles / km	Reported length, miles
2004	142.3 / 229.0	142
2005	131.8 / 212.0	131.6

Table VII. Average course segment length.	
Year	Average course segment length, m
2004	88.6
2005	72.3

Table VIII. Calculated turn radius and notional diameter using SSF = 1.02.

Speed, mph	Radius, m (calculated)	Diameter, m	Diameter, m (notional)	Equivalent square root
5	0.4998	0.9996	1	1
10	1.9992	3.9985	4	2
15	4.4983	8.9966	9	3
20	7.9970	15.9940	16	4
25	12.4953	24.9906	25	5
30	17.9932	35.9864	36	6
35	24.4908	48.9816	49	7
40	31.9880	63.9759	64	8
45	40.4848	80.9695	81	9
50	49.9812	99.9624	100	10
55	60.4772	120.9545	121	11
60	71.9729	143.9458	144	12

Table IX. Course segment speed.				
Speed, mph	2004		2005	
	Number	Percent (cumulative)	Number	Percent (cumulative)
< 11	406	15.7	810	27.6
11 - 15	703	42.9	318	38.4
16 - 20	211	51.1	679	61.6
21 - 25	870	84.7	379	74.5
26 - 30	55	86.8	458	90.1
31 - 35	0	86.8	59	92.1
36 - 40	245	96.3	136	96.8
41 - 45	2	96.4	95	100.0
> 45	93	100.0	N/A	N/A

Table X. Course segments per group.					
Speed, mph	Number		Speed, mph (cumulative)	Percent (cumulative)	
	2004	2005		2004	2005
< 11	406	810	2 - 10	15.7	27.6
11 - 20	914	997	2 - 20	51.1	61.6
21 - 30	925	837	2 - 30	86.8	90.1
31 - 40	245	195	2 - 40	96.3	96.8
> 40	95	95	All	100.0	100.0

Table XI. Total distance per group.					
Speed, mph	**Distance, km**		**Speed, mph (cumulative)**	**Percent (cumulative)**	
	2004[a]	**2005**[b]		**2004**[c]	**2005**[d]
< 11	13.6	24.6	2 - 10	5.9	11.6
11 - 20	41.6	54.4	2 - 20	24.1	37.3
21 - 30	109.7	94.5	2 - 30	72.0	81.8
31 - 40	39.4	25.9	2 - 40	89.2	94.1
> 40	24.7	12.7	All	100.0	100.0

Notes:

[a] Distance may not sum to 229.0 km due to rounding error.

[b] Distance may not sum to 212.0 km due to rounding error.

[c] Cumulative percentages are based on a total course length of 229.0 km.

[d] Cumulative percentages are based on a total course length of 212.0 km.

Table XII. Reportable change in bearing.				
Change in bearing	2004		2005	
	Number	Percent	Number	Percent
<= 5[a]	1345	52.0	1979	67.5
> 5	1240	48.0	955	32.5
> 10	613	23.7	428	14.6
> 15	295	11.4	225	7.7
> 20	145	5.6	120	4.1
> 25	69	2.7	66	2.2
> 30	40	1.5	39	1.3
> 35	24	0.9	21	0.7
> 40	13	0.5	12	0.4
> 45	10	0.4	2	0.1
> 50	5	0.2	0	0.0

Note:

[a] Calculated by difference. The RDDF analysis application calculates the number of changes in bearing that exceed a reportable change in bearing (see Appendix A).

Table XIII. 2004 and 2005 GCE course completion times given notional course-wide speed limits.

Year	Notional course-wide speed limit, mph	Number of segments	Total length, km	Time, hours
2004	35[a]	340	64.1	6.66
	30	340	64.1	6.66
	25	395	70.6	7.14
	20	1265	173.8	8.22
	15	1476	187.8	10.17
2005	35	231	30.9	6.29
	30	290	38.6	6.41
	25	748	98.4	6.81
	20	1127	133.1	7.64
	15	1806	175.6	9.45

Note:

[a] The results are identical to those for 30 mph because the 2004 GCE RDDF does not define any course segments with a speed of 35 mph.

Table XIV. Challenge vehicle platform.

Challenge vehicle platform	Type	2004 QID	2004 GCE	2005 GCE
Commercially-available SUV	1	6	4	7
Commercially-available truck	2	2	2	4
Commercially-available ATV[a]	3	8	5	6
Military service vehicle	4	2	2	3
Purpose-built vehicle	5	6	1	2
TOTAL		25[b]	15[b]	23[c]

Notes:

[a] "Commercially-available ATV" includes both 4- and 6-wheeled commercially-available ATVs.

[b] Team 2004-03 selected a motorcycle as challenge vehicle platform ([92]).

[c] Team 2005-18 selected a 2005 Ford E-350 Van as challenge vehicle platform ([197], p. 5).

Table XV. Team vehicles (2004 QID and GCE participants).		
Team	**Vehicle**	**Type**
2004-01	"purpose-built"	5
2004-02	1994 Jeep Grand Cherokee Limited 4x4	1
2004-03	[motorcycle]	
2004-04	1993 Isuzu Trooper	1
2004-05	"air bag suspended class 1 race vehicle"	5
2004-06	2003 Toyota Tundra (SR5 V8 Access Cab)	2
2004-07	1994 Ford F-150 4x4	2
2004-08	1987 Chevrolet Suburban[42]	1
2004-09	2004 Acura MDX[40]	1
2004-10	M998 HMMWV	4
2004-11	"Coyote vehicle"	5
2004-12	[purpose-built vehicle]	5
2004-13	2003 ATV Prowler[41]	3
2004-14	"Tomcar" (model TM27G)	3
2004-15	1992 Jeep Cherokee	1
2004-16	MAX IV ATV	3
2004-17	1996 Chevy Tahoe	1
2004-18	Honda Rincon ATV	3
2004-19	[purpose-built vehicle]	5
2004-20	Polaris Ranger Series 11	3
2004-21	Kawasaki KFX ATV	3
2004-22	2003 Honda 4x4 ATV	3
2004-23	Oshkosh Trucks MTVR Model MK23	4
2004-24	[purpose-built vehicle]	5
2004-25	"off-road, four-wheel drive utility cart made by Club Car"	3

Table XVI. Team vehicles (2005 GCE participants).		
Team	**Vehicle**	**Type**
2005-01	1994 Jeep Grand Cherokee Limited 4x4	1
2005-02	"... all terrain vehicle custom built ..."	5
2005-03	2003 Toyota Tundra (SR5 V8 Access Cab model)	2
2005-04	2005 Polaris Ranger 6x6	3
2005-05	2005 Dodge Ram 2500	2
2005-06	2005 Ford Escape Hybrid	1
2005-07	1987 Chevrolet Suburban[42]	1
2005-08	2005 Ford F-250 SuperDuty	2
2005-09	2004 Ford Explorer Sport Trac	1
2005-10	2001 Nissan Xterra	1
2005-11	2004 Kawasaki KFX700	3
2005-12	2005 GMC Canyon	2
2005-13	1986 AM General M998 HMMWV	4
2005-14	1999 AM General H1 Hummer	1
2005-15	2003 ATV Prowler	3
2005-16	2004 Volkswagen Touareg R5	1
2005-17	MAX IV ATV	3
2005-18	2005 Ford E-350 Van	
2005-19	Spider Light Strike Vehicle	4
2005-20	"... custom-made chassis ..."	5
2005-21	Oshkosh MTVR Model MK23 Standard Cargo Truck	4
2005-22	Ingersoll-Rand Club Car XRT-1500	3
2005-23	Ingersoll-Rand Club Car XRT-1500	3

Table XVII. Team vehicle closest match (2004 QID and GCE participants).		
Team	**Closest match**	**SSF**
2004-01	N/A	
2004-02	1993 2001 2003 Jeep Grand Cherokee	1.11
2004-03	N/A	
2004-04	1992 1994 Isuzu Trooper 4-DR 4x4	1.07
2004-05	N/A	
2004-06	2000 2002 2003 Toyota Tundra Access Cab 4x2	1.16
2004-07	1985 1996 Ford F-150 4x4 Pickup	1.20
2004-08	1982 1985 1991 Chevrolet K20/V20 4x4 Suburban	1.02
2004-09	2001 2002 2003 Acura MDX 4-DR 4x4	1.29
2004-10	N/A - Military service vehicle	
2004-11	N/A	
2004-12	N/A	
2004-13	N/A - Commercially-available ATV	
2004-14	N/A - Military service vehicle	
2004-15	1997 2001 Jeep Cherokee 4x4	1.08
2004-16	N/A	
2004-17	1995 1998 1999 Chevrolet Tahoe 4-DR 4x4	1.13
2004-18	N/A - Commercially-available ATV	
2004-19	N/A	
2004-20	N/A - Commercially-available ATV	
2004-21	N/A - Commercially-available ATV	
2004-22	N/A - Commercially-available ATV	
2004-23	N/A - Military service vehicle[a]	1.00
2004-24	N/A	
2004-25	N/A - Commercially-available ATV	

Note:

[a] The author was unable to determine the height of vehicle CG reported by the manufacturer at the time of the 2004 and 2005 GCE ([255]) because the figure providing dimensions is illegible. However, the manufacturer later reported a track

width of 80.8 in and height of vehicle CG of 40.4 in ([256]). SSF was calculated for these values.

Table XVIII. Team vehicle closest match (2005 GCE participants).		
Team	**Closest match**	**SSF**
2005-01	1993 2001 2003 Jeep Grand Cherokee 4x4	1.11
2005-02	N/A	
2005-03	2000 2002 2003 Toyota Tundra Access Cab 4x2	1.16
2005-04	N/A - Commercially-available ATV	
2005-05	2002 Dodge Ram 1500 Quad Cab 4x4	1.15
2005-06	N/A[a]	1.17
2005-07	1982 1985 1991 Chevrolet K20/V20 4x4 Suburban	1.02
2005-08	1981 1985 1997 Ford F250 4x4 Pickup	1.11
2005-09	2001 2002 2003 Ford Explorer Sport 2-DR 4x4	1.07
2005-10	2000 2001 2002 Nissan Xterra 4-DR 4x4	1.12
2005-11	N/A - Commercially-available ATV	
2005-12	N/A[b]	
2005-13	N/A - Military service vehicle	
2005-14	N/A	
2005-15	N/A - Commercially-available ATV	
2005-16	N/A[c]	
2005-17	N/A - Commercially-available ATV	
2005-18	N/A	
2005-19	N/A - Military service vehicle	
2005-20	N/A	
2005-21	N/A - Military service vehicle[d]	1.00
2005-22	N/A - Commercially-available ATV	
2005-23	N/A - Commercially-available ATV	

Notes:

[a] The author was unable to determine SSF for the Ford Escape Hybrid, which was new for model year 2005. A commercial used vehicle search service ([257]) reported a SSF of 1.17 for a "2005 Ford Escape 4-DR". A SSF of 1.17 is used herein.

[b] The GMC Canyon was new for model year 2004.

[c] The Volkswagen Touareg was new for model year 2004.

[d] The author was unable to determine the height of vehicle CG reported by the manufacturer at the time of the 2004 and 2005 GCE ([255]) because the figure providing dimensions is illegible. However, the manufacturer later reported a track width of 80.8 in and height of vehicle CG of 40.4 in ([256]). SSF was calculated for these values.

Table XIX. Typical values for the kinetic coefficient of friction.		
Material 1	**Material 2**	μ_k
Rubber	Asphalt (dry)	0.50 – 0.80
Rubber	Asphalt (wet)	0.25 – 0.75
Rubber	Concrete (dry)	0.60 – 0.85
Rubber	Concrete (wet)	0.45 – 0.75

Table XX. Turning circle for selected challenge vehicles[a].			
Team	**Edmunds[b] Turning Circle, ft**	**Cars.com[c] Turning Radius, ft**	**MotorTrend[d] Turning Circle, ft**
2004-02 and 2005-01	36.6	N/A	N/A
2004-06 and 2005-03	44.9 ([258])		
2004-09	38.0	19.0	38.0
2004-14	27.9[e]		
2004-17		N/A	42.9[f]
2-DR 4x4 LS/LT	38.1		
4-DR 4x4 LS	42.9		
2004-23	85.4[g]		
2004-24	0.0[h]		
2004-25	10.0[i]		
2005-04	N/A[j]		
2005-06	37.7	18.3	35.4
2005-08[k]			
Low:	46.1	23.1	47.7
High:	56.5	28.3	56.5
2005-09	43.1	21.5	43.1
2005-10	N/A	17.7	35.4[l]
2005-12[m]	44.6	N/A	44.3
2005-14	53.0	26.5[n]	26.5[o]
2005-16	N/A	19.0	N/A
2005-17	9.0[p]		
2005-18	48.0	24.0	48.0
2005-21	58.0[q]		
2005-22 and 2005-23	23.0[r]		

Notes:

[a] In general, vehicle manufacturers' websites, including their "certified pre-owned vehicle" sections, did not report detailed information for past models of vehicles, such as those selected as challenge vehicle platform by teams participating in the 2004 QID and GCE and 2005 GCE. As a result, the author surveyed commercial used vehicle search services to determine values for turning circle and SSF.

[b] Edmunds, Inc. ("Edmunds") reported "turning circle" ([41]).

[c] Cars.com ("Cars.com") reported "turning radius" ([42]).

[d] MotorTrend Magazine ("MotorTrend") reported "curb-to-curb turning circle" ([43]).

[e] Team 2004-14 reported a "turn radius" of "27.9 ft or 8.5 m" ([132], p. 1). Tomcar did not report turn radius or turning circle information for the Tomcar model TM27G ([259]). However a turning circle of 55.8 ft exceeds that of all other challenge vehicles with the exceptions of Teams 2004-23 and 2005-21, and possibly Team 2005-08. The author considers it unlikely a vehicle marketed primarily to off-road enthusiasts would have a turning circle greater than the Teams 2004-23 and 2005-21 challenge vehicle, and concluded the "turn radius" reported by Team 2004-14 was a turning circle. A turning circle of 55.8 ft is used herein.

[f] MotorTrend reported the turning circle was 13,076 mm ([43]).

[g] The manufacturer reported "wall-to-wall" turning circle, and reported the turning circle of the Team 2004-23 challenge vehicle platform was 85.4 ft ([255]). Team 2004-23 reported a "minimum turning radius" of 42.7 feet ([159]), or half of the turning circle reported by the manufacturer.

[h] Team 2004-24 reported "turning radius", and stated: "Inter segment articulation provides a turning radius as small as 30 feet for higher speed turning. Low speed turning down to zero radius is accomplished with differential drive to the motors." ([161], p. 2).

[i] Team 2004-25 reported a "turning radius" of "approximately 10 feet" ([49], p. 2).

[j] Team 2005-04 reported "turn radius", and stated: "The Polaris Ranger was selected due to its agility, off-road driving capability, small turn radius and ease of modification." ([169], p. 3). However, Team 2005-04 did not report the turning radius of the challenge vehicle.

[k] In general, American motor vehicle manufacturers support many more vehicle options than foreign motor vehicle manufacturers. For example, the 2005 Ford F-250 SuperDuty was available in three trim levels: XL, XLT, and Lariat; three cab options:

Standard (Regular) cab, Extended (Super) cab, and Crew cab; and two bed lengths: short and long. As a result, each 2005 Ford F-250 SuperDuty may have a 137-, 142-, 156-, 158-, or 172-inch wheelbase, each with a different turn radius. Rather than report the turning radius for every possible combination of options, only the low and high values are recorded herein as the best and worst possible case, respectively.

[l] MotorTrend reported the turning circle was 10,790 mm ([43]).

[m] Team 2005-12 stated: "[The challenge vehicle] has... a turning radius of 13 meters." ([185], p. 3). A "turning radius" of 13 m corresponds to a turning circle of 85.3 ft (26.0 m). Edmunds and MotorTrend ([41] and [43]) reported the turning circle of a 2005 GMC Canyon (Crew Cab) is 44.6 ft (13.6 m) and 44.3 ft (13.5 m), respectively. The turning circle reported by Team 2005-12 is approximately twice these values. As a result, the author concluded the "turning radius" reported by Team 2005-12 was a turning circle. The turning circles reported by commercial used vehicle search services is used herein.

[n] Cars.com ([42]) did not report detailed information for AM General H1 Hummer model years prior to 2000. The turning radius for a 2000 AM General H1 Hummer is used herein.

[o] MotorTrend reported the turning circle was 8,077 mm, which equals the turning radius reported by Cars.com or half the turning circle reported by Edmunds. The author concluded the turning circle reported by MotorTrend is a turning radius, not a turning circle.

[p] Team 2005-17 reported a "minimum turning radius" of "9ft" ([140], p. 3). However, Team 2005-17 later stated: "This vehicle was chosen because: ... it has a very small turning radius, about 1.2 m..." ([196], p. 557). A turning radius of 1.2 m is approximately 3.9 ft. The manufacturer did not report the turning radius or turning circle of the MAX IV ATV ([260]). As a result, the author was unable to resolve the discrepancy. A turning radius of 9.0 ft is used herein.

[q] Team 2005-21 reported "turning radius", and stated: "Rear steer has been added to [the challenge vehicle] to give it a 29-foot turning radius." ([160], p. 3).

[r] Teams 2005-22 and 2005-23 reported "turning radius", and stated: "This vehicle suits our application well with an 11.5' turning radius..." ([58], p. 2 and [164], p. 2). Teams 2005-22 and 2005-23 later stated: " The XRT 1500 is extremely agile with a turning radius of 3.5 m.", or approximately 11.5 ft ([59], p. 710).

Table XXI. Calculated rollover speed for selected challenge vehicles.				
Team	**Rollover speed, mph**			**SSF**
	Edmunds ([41])	**Cars.com ([42])**	**MotorTrend ([43])**	
2004-02 and 2005-01	17.4	N/A	N/A	1.11
2004-06 and 2005-03	19.7			1.16
2004-09	19.2	19.2	19.2	1.29
2004-17		N/A	19.1	
2-DR 4x4 LS/LT	17.9			1.13
4-DR 4x4 LS	19.1			1.13
2004-23	25.3			1.00
2005-06	18.2	17.9	17.6	1.17
2005-08				
Low:	19.6	19.6	19.9	1.11
High:	21.7	21.7	21.7	1.11
2005-09	18.6	18.6	18.6	1.07
2005-10	N/A	17.2	17.2	1.12
2005-12	20.0	N/A	19.9	1.20
2005-14	20.1	20.1	20.1	1.02
2005-16	N/A	17.0	N/A	1.02
2005-18	19.1	19.1	19.1	1.02
2005-21	20.8			1.00

Table XXII. 2004 GCE standard questions.	
1.a.1	Describe the means of ground contact. Include a diagram showing the size and geometry of any wheels, tracks, legs, and/or other suspension components.
1.a.2	Describe the method of Challenge Vehicle locomotion, including steering and braking.
1.a.3	Describe the means of actuation of all applicable components.
1.b.1	What is the source of Challenge Vehicle power?
1.b.2	Approximately how much maximum peak power (expressed in Watts) does the Challenge Vehicle consume?
1.b.3	What type and how much fuel will be carried by the Challenge Vehicle?
1.c.1	What kind of computing systems (hardware) does the Challenge Vehicle employ? Describe the number, type, and primary function of each.
1.c.2	Describe the methodology for the interpretation of sensor data, route planning, and vehicle control. How does the system classify objects? How are macro route planning and reactive obstacle avoidance accomplished? How are these functions translated into vehicle control?
1.d.1	What types of map data will be pre-stored on the vehicle for representing the terrain, the road network, and other mobility or sensing information? What is the anticipated source of this data?
1.e.1	What sensors does the challenge vehicle use for sensing the environment, including the terrain, obstacles, roads, other vehicles, etc.? For each sensor, give its type, whether it is active or passive, its sensing horizon, and its primary purpose?
1.e.2	How are the sensors located and controlled? Include any masts, arms, or the tethers that extend from the vehicle?
1.f.1	What sensors does the challenge vehicle use for sensing vehicle state?

1.f.2	How does the vehicle monitor performance and use such data to inform decision making?
1.g.1	How does the system determine its geolocation with respect to the Challenge Route?
1.g.2	If GPS is used, how does the system handle GPS outages?
1.g.3	How does the system process and respond to Challenge Route boundaries?
1.h.1	Will any information (or any wireless signals) be broadcast from the Challenge Vehicle? This should include information sent to any autonomous refueling/servicing equipment.
1.h.2	What wireless signals will the Challenge Vehicle receive?
1.i.1	Does the system refuel during the race? If so, describe the refueling procedure and equipment.
1.i.2	Are any additional servicing activities planned for the checkpoint? If so, describe the function and equipment.
1.j.1	How will the vehicle be controlled before the start of the challenge and after its completion? If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.
1.j.2	If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.
2.a	What tests have already been conducted with the Challenge Vehicle or key components? What were the results?
2.b	What tests will be conducted in the process of preparing for the Challenge?
3.a	What is the top speed of the vehicle?
3.b	What is the maximum range of the vehicle?

3.c	List all safety equipment on-board the Challenge Vehicle, including:
3.c.1	Fuel containment
3.c.2	Fire suppression
3.c.3	Audio and visual warning devices
3.d.1	How does the Challenge Vehicle execute emergency stop commands? Describe in detail the entire process from the time the on-board E-Stop receive outputs a stop signal to the time the signal is cleared and the vehicle may proceed. Include descriptions of both the software controlled stop and the hard stop.
3.d.2	Describe the manual E-Stop switch(es). Provide details demonstrating that this device will prevent unexpected movement of the vehicle once engaged.
3.d.3	Describe in detail the procedure for placing the vehicle in "neutral", how the "neutral" function operates, and any additional requirements for safely manually moving the vehicle. Is the vehicle towable by a conventional tow truck?
3.e.1	Itemize all devices on the Challenge Vehicle that actively radiate EM energy, and state their operating frequencies and power output. (E.g., lasers, radar apertures, etc.).
3.e.2	Itemize all devices on the Challenge Vehicle that may be considered a hazard to eye or ear safety and their OSHA classification level.
3.e.3	Describe any safety measures and/or procedures related to all radiators.
3.f.1	Describe any Challenge Vehicle properties that may conceivably cause environmental damage, including damage to roadways and off-road surfaces.
3.f.2	What are the maximum physical dimensions (length, width, and height) and weight of the vehicle?

3.f.3	What is the area of the vehicle footprint? What is the maximum ground pressure?

Table XXIII. 2005 GCE standard questions.	
1	Vehicle Description
1.1	Describe the vehicle. If it is based on a commercially available platform, provide the year, make and model. If it uses a custom-built chassis or body, describe the major characteristics. If appropriate, please provide a rationale for the choice of this vehicle for the DGC.
1.2	Describe the unique vehicle drive-train or suspension modifications made for the DGC including fuel-cells or other unique power sources.
2	Autonomous Operations
2.1	Processing
2.1.1	Describe the computing systems (hardware and software) including processor selection, complexity considerations, software implementation and anticipated reliability.
2.1.2	Provide a functional block diagram of the processing architecture that describes how the sensing, navigation, and actuation are coupled to the processing element(s) to enable autonomous operation. Show the network architecture and discuss the challenges faced in realization of the system.
2.1.3	Describe unique methods employed in the development process, including model-driven design or other methods used.
2.2	Localization
2.2.1	Explain the GPS system used and any inertial navigation systems employed during GPS outages (as in tunnels). Include a discussion of component errors and their effort on system performance.
2.2.2	If map data was an integral part of the vehicles navigation system, describe the requirements for this data and the way in which it was used.
2.3	Sensing

2.3.1	Describe the location and mounting of the sensors mounted on the vehicle. Include a discussion of sensor range and field of view. Discuss any unique methods used to compensate for conditions such as vibration, light level, rain, or dust.
2.3.2	Discuss the overall sensing architecture, including any fusion algorithms or other means employed to build models of the external environment.
2.3.3	Describe the internal sensing system and architecture used to sense the vehicle state.
2.3.4	Describe the sensing-to-actuation system used for waypoint following, path finding, obstacle detection, and collision avoidance. Include a discussion of vehicle models in terms of braking, turning, and control of the accelerator.
2.4	Vehicle Control
2.4.1	Describe the methods employed for common autonomous operation contingencies such as missed-waypoint, vehicle-stuck, vehicle-outside-lateral-boundary-offset, or obstacle-detected-in-path.
2.4.2	Describe the methods used for maneuvers such as braking, starting on a hill, or making a sharp turn without leaving the boundaries.
2.4.3	Describe the method for integration of navigation information and sensing information.
2.4.4	Discuss the control of the vehicle when it is not in autonomous mode.
2.5	System Tests
2.5.1	Describe the testing strategy to ensure vehicle readiness for DGC, including a discussion of component reliability, and any efforts made to simulate the DGC environment.
2.5.2	Discuss test results and key challenges discovered.

Table XXIV. State sensors in use by 2004 QID and GCE participants.			
Team	**Number**	**Manufacturer**	**Model number**
2004-01	(1)	**-unknown-**	**-unknown-** (“engine RPM”)
2004-01	(1)	**-unknown-**	**-unknown-** (“intake manifold pressure”)
2004-01	(1)	**-unknown-**	**-unknown-** (“brake settings”)
2004-01	(1)	**-unknown-**	**-unknown-** (“brake hydraulic pressure”)
2004-01	(1)	**-unknown-**	**-unknown-** (“fuel level”)
2004-01	(1)	**-unknown-**	**-unknown-** (“water temperature”)
2004-01	(1)	**-unknown-**	**-unknown-** (“transmission gear position”)
2004-01	(1)	**-unknown-**	**-unknown-** (“throttle position”)
2004-01	(1)	**-unknown-**	**-unknown-** (“steering angle”)
2004-02	**-n-**	**-unknown-**	**-unknown- (**“Some of the above mentioned sensors...”)
2004-02	1	OEM	OBD-II
2004-03	(1)	**-unknown-**	**-unknown-** (AOE, “steering position”)
2004-03	(1)	**-unknown-**	**-unknown-** (potentiometer, “steering position”)
2004-04	1	Honeywell	RT600-360-01 (“steering angle”)
2004-04	1	Motion Systems	85615 (“throttle state”)
2004-04	1	OEM	RPM sensor (“throttle response”)
2004-04	1	Motion Systems	85615 (“transmission gear state”)
2004-04	(1)	Honeywell	ML500PS1PC (“brake pressure”)
2004-05	1	**-unknown-**	**-unknown-** (“engine tachometer”)
2004-05	1	**-unknown-**	**-unknown-** (“shifter position sensor”)

2004-05	2	**-unknown-**	**-unknown-** (pressure transducers, “feedback from the brake lines”)
2004-05	4	**-unknown-**	**-unknown-** (pressure transducers)
2004-05	4	**-unknown-**	**-unknown-** (linear motion position sensor, “shock absorber extension”)
2004-05	1	**-unknown-**	**-unknown-** (linear motion position sensor, “throttle position”)
2004-05	1	**-unknown-**	**-unknown-** (linear motion position sensor, “steering rack position”)
2004-05	1	**-unknown-**	**-unknown-** (“cooling water temperature sensor”)
2004-05	**-n-**	**-unknown-**	**-unknown-** (“certain other sensors”)
2004-07	1	**-unknown-**	**-unknown-** (potentiometer, “position of the steering column”)
2004-08	1	OEM	fuel sender (fuel level)
2004-08	1	**-unknown-**	**-unknown-** (“optical sensor”, steering position)
2004-08	2	**-unknown-**	**-unknown-** (ten-turn potentiometer, brake and accelerator pedal position)
2004-09	(1)	**-unknown-**	**-unknown-** (“engine speed”)
2004-09	(1)	**-unknown-**	**-unknown-** (“steering wheel position”)
2004-10	**-n-**	**-unknown-**	**-unknown-** (OE)
2004-10	**-n-**	**-unknown-**	**-unknown-** (“potentiometers”)
2004-10	**-n-**	**-unknown-**	**-unknown-** (“rotational variable differential transformers (RVDT)”)
2004-10	**-n-**	**-unknown-**	**-unknown-** (“current” sensor)
2004-10	**-n-**	**-unknown-**	**-unknown-** (“voltage” sensor)
2004-11	1	**-unknown-**	**-unknown-** (“tachometer”, “engine speed data”)
2004-12	2	Ultra Motion	2-B.125-DC426_12-4-P-/4-300 (linear potentiometer, “wheel angle for front and rear”)
2004-12	1	Omron	E2E-CR8B1 (“engine speed”)
2004-13	(1)	**-unknown-**	**-unknown-** (“state of the vehicle's transmission”)
2004-13	(1)	**-unknown-**	**-unknown-** (“throttle position”)

2004-13	(1)	**-unknown-**	**-unknown-** ("braking pressure")
2004-13	1	**-unknown-**	**-unknown- ("**absolute encoder", "steering rate and angle")
2004-14	(1)	**-unknown-**	**-unknown-** ("state of the vehicle's transmission")
2004-14	(1)	**-unknown-**	**-unknown-** ("throttle position")
2004-14	(1)	**-unknown-**	**-unknown-** ("braking pressure")
2004-14	1	**-unknown-**	**-unknown-** ("angular encoder", "steering rate and angle")
2004-15	(1)	**-unknown-**	**-unknown-** ("brake position")
2004-15	(1)	**-unknown-**	**-unknown-** ("throttle position")
2004-15	(1)	**-unknown-**	**-unknown-** ("RPM")
2004-15	(1)	**-unknown-**	**-unknown-** ("low oil pressure")
2004-15	(1)	**-unknown-**	**-unknown-** ("transmission shifter position")
2004-15	(1)	**-unknown-**	**-unknown-** ("transfer case shifter position")
2004-15	(1)	**-unknown-**	**-unknown-** ("air conditioning information")
2004-15	(1)	**-unknown-**	**-unknown-** (stepper motor, "steering position")
2004-17	1	OEM	OBD-II ("engine temperature", "engine RPM", and "present gear")
2004-18	(1)	**-unknown-**	**-unknown-** ("engine is running")
2004-18	(1)	**-unknown-**	**-unknown-** ("brakes are applied")
2004-18	(1)	**-unknown-**	**-unknown-** ("acceleration is applied")
2004-18	(1)	**-unknown-**	**-unknown-** ("position of the steering motor")
2004-18	**-n-**	**-unknown-**	**-unknown-** ("temperature sensors")
2004-20	(1)	**-unknown-**	**-unknown-** ("engine RPM")
2004-20	(1)	**-unknown-**	**-unknown-** ("driveshaft RPM")
2004-20	**-n-**	**-unknown-**	**-unknown-** ("voltage")

2004-20	**-n-**	**-unknown-**	**-unknown-** (“temperature”)
2004-20	**-n-**	**-unknown-**	**-unknown-** (“actuators”, “position and velocity”)
2004-21	(1)	**-unknown-**	**-unknown-** (“fuel”)
2004-21	**-n-**	**-unknown-**	**-unknown-** (“temperature”)
2004-21	**-n-**	**-unknown-**	**-unknown-** (“electrical output”)
2004-21	**-n-**	**-unknown-**	**-unknown-** (“etcetera”)
2004-22	3	**-unknown-**	**-unknown-** (“temperature sensors”, “engine, oil, and outside temperatures”)
2004-22	(4)	SpaceAge Control	**-unknown-** (string potentiometer, “actual position of the shock (compressed or uncompressed)”)
2004-23	(1)	**-unknown-**	**-unknown-** (“vehicle and actuator sensors”, “throttle”)
2004-23	(1)	**-unknown-**	**-unknown-** (“vehicle and actuator sensors”, “brakes”)
2004-23	(1)	**-unknown-**	**-unknown-** (“vehicle and actuator sensors”, “engine condition”)
2004-24	16	**-unknown-**	**-unknown-** (“pressure sensors”, suspension and steering)
2004-24	2	**-unknown-**	**-unknown-** (“pressure sensors”, brake actuators)
2004-24	1	**-unknown-**	**-unknown-** (“pressure sensors”, storage tanks)
2004-24	(1)	**-unknown-**	**-unknown-** (“voltage sensors”, batteries)
2004-24	(1)	**-unknown-**	**-unknown-** (“current sensors”, batteries)
2004-24	(1)	**-unknown-**	**-unknown-** (“voltage sensors”, generator)
2004-24	(1)	**-unknown-**	**-unknown-** (“speed sensors”, generator)
2004-24	(1)	**-unknown-**	**-unknown-** (“water temperature sensors”, generator)
2004-25	1	**-unknown-**	**-unknown-** (linear actuator, “position and velocity of the brake... [motor]”)
2004-25	1	Bodine Electric	42A-5N (model number 0941 integral OE, “position and velocity of the... steering... [motor]”)
2004-25	1	Japan Servo	DME 60B6HF (integral OE, “position and velocity of the... throttle [motor]”)
2004-25	2	**-unknown-**	**-unknown-** (“battery voltage for each on-board battery”)

2004-25	**-n-**	**-unknown-**	**-unknown-** ("temperature inside all electronic enclosures")

Table XXV. Environment sensors in use by 2004 QID and GCE participants.

Team	Number	Manufacturer	Model number	Sensor Type
2004-01	1	**-unknown-**	**-unknown-** (“digital camera”)	VISION
2004-01	1	**-unknown-**	**-unknown-** (“monochrome camera, sensitive to near IR”)	VISION
2004-01	**-n-**	**-unknown-**	**-unknown-** (“ultrasonic sensors”)	X
2004-01	2	SICK	**-unknown-** (LMS 211-30106 or -30206)	LIDAR
2004-02	1	AVT	**-unknown-** (“Dolphin”)	VISION
2004-02	1	FLIR	A20M	VISION
2004-02	(3)	Point Grey	Bumblebee	STEREO
2004-02	1	Epsilon Lambda	ELSC71-1A	RADAR
2004-02	1	SICK	LMS 211-30206	LIDAR
2004-02	4	2004-02	MetalSense B1 (“touch sensor”)	X
2004-03	2	Cognex	**-unknown-** (“ethernet cameras”)	STEREO
2004-03	1	**-unknown-**	**-unknown-** (“color camera”)	VISION
2004-03	1	Epsilon Lambda	ELSC71-1A	RADAR
2004-04	1	Videre Design	**-unknown-** (“stereo vision system”)	STEREO
2004-04	1	SICK	LMS 200-30106 (“rotating”)	LIDAR
2004-04	1	**-unknown-**	**-unknown-** (“long-range RADAR”)	RADAR
2004-04	1	SICK	LMS 200-30106 (“fixed”)	LIDAR
2004-04	3	Preco	**-unknown-** (“PreView”)	RADAR
2004-04	3	**-unknown-**	**-unknown-** (“stationary cameras”)	VISION
2004-05	14	**-unknown-**	**-unknown-** (“SONAR array”)	X

2004-05	2	**-unknown-**	**-unknown-** (“depth finders”)	X
2004-05	2	SICK	**-unknown-** (“LMS 291”)	LIDAR
2004-05	2	**-unknown-**	**-unknown-** (“conductivity sensor”)	X
2004-05	7	**-unknown-**	**-unknown-** (“tactile sensor”)	X
2004-05	1	Eaton	**-unknown-** (“Vorad VBOX 83001-001”)	RADAR
2004-05	1	Point Grey	Bumblebee	STEREO
2004-06	1	2004-06	Digital Auto Drive (DAD)	STEREO
2004-07	1	SICK	**-unknown-** (LIDAR)	LIDAR
2004-07	1	Epsilon Lambda	ELSC71-1A	RADAR
2004-07	1	**-unknown-**	**-unknown-** (“ground whisker”)	X
2004-07	1	FLIR	Omega	VISION
2004-07	2	Sony	DFW-VL500	VISION
2004-08	4	Laseroptronix	LDM 800-RS232	LIDAR
2004-08	1	Laseroptronix	Sea-Lynx	VISION/LIDAR
2004-08	2	Cohu	1330	VISION
2004-09	1	**-unknown-**	**-unknown-** (“vibration sensor”)	X
2004-09	1	SICK	**-unknown-** (“LMS 211 or 221”)	LIDAR
2004-09	1	**-unknown-**	**-unknown-** (“generic, high-resolution color digital camera”)	VISION
2004-10	1	Riegl	LMS-Q140i	LIDAR
2004-10	3	SICK	**-unknown-** (LIDAR)	LIDAR
2004-11	3	Polaroid	6500	X
2004-11	1	**-unknown-**	**-unknown-** (“scanning laser range finder”)	LIDAR
2004-11	1	**-unknown-**	**-unknown-** (“long-range laser ranger”)	LIDAR

2004-11	1	Omnivision	**-unknown-** (“digital image sensor array”)	VISION
2004-12	3	**-unknown-**	**-unknown-** (“ultrasonic distance sensors”)	X
2004-12	1	SICK	LMS 291-S05	LIDAR
2004-13	(24)	Rockwell Automation	**-unknown-** (“photoelectric sensors”)	X
2004-13	4	SICK	**-unknown-** (LIDAR)	LIDAR
2004-13	**-n-**	**-unknown-**	**-unknown-** (“ultrasonic range finders”)	X
2004-13	1	**-unknown-**	**-unknown-** (“video camera”)	VISION
2004-13	1	Epsilon Lambda	**-unknown-** (RADAR)	RADAR
2004-13	1	**-unknown-**	**-unknown-** (accelerometer, “roughness of the terrain”)	X
2004-14	**-n-**	**-unknown-**	**-unknown-** (“tactile sensors”)	X
2004-14	**-n-**	**-unknown-**	**-unknown-** (“video cameras”)	VISION
2004-14	4	SICK	**-unknown-** (LIDAR)	LIDAR
2004-14	(24)	Rockwell Automation	**-unknown-** (“photoelectric sensors”)	X
2004-14	**-n-**	**-unknown-**	**-unknown-** (“ultrasonic range finder”)	X
2004-14	1	Epsilon Lambda	**-unknown-** (RADAR)	RADAR
2004-14	1	**-unknown-**	**-unknown-** (accelerometer, “roughness of the terrain”)	X
2004-15	1	Eaton	EVT-300	RADAR
2004-15	**-n-**	**-unknown-**	**-unknown-** (“tactile sensors”)	X
2004-15	5	Polaroid	6500	X
2004-15	1	SICK	LMS 211-30206	LIDAR
2004-16	**-n-**	**-unknown-**	**-unknown-** (RADAR)	RADAR
2004-16	**-n-**	**-unknown-**	**-unknown-** (SONAR)	X
2004-16	2	SICK	**-unknown-** (LIDAR)	LIDAR

2004-16	2	**-unknown-**	**-unknown-** (“passive cameras”)	VISION
2004-17	1	Point Grey	Dragonfly (“road-following camera”)	VISION
2004-17	2	SICK	LMS 221-30206	LIDAR
2004-17	4	Point Grey	Dragonfly (“stereovision cameras”)	STEREO
2004-18	1	**-unknown-**	**-unknown-** (“stereo camera system”)	STEREO
2004-18	1	SICK	LMS 220-30106	LIDAR
2004-18	3	**-unknown-**	**-unknown-** (“doppler radars”)	RADAR
2004-19	1	**-unknown-**	**-unknown-** (“stereo vision system”)	STEREO
2004-19	1	SICK	DME 2000	LIDAR
2004-19	3	**-unknown-**	**-unknown-** (“ultrasonic rangefinders”)	X
2004-20	1	SICK	LMS 221-30206	LIDAR
2004-20	1	Eaton	EVT-300	RADAR
2004-20	**-n-**	**-unknown-**	**-unknown-** (“water sensors”)	X
2004-20	**-n-**	**-unknown-**	**-unknown-** (“ultrasonic sonars”)	X
2004-20	1	Unibrain	Fire-i 400	VISION
2004-21	1	Epsilon Lambda	ELSC71-1A	RADAR
2004-21	1	SensComp	Developer's Kit	X
2004-22	1	2004-22	Video System (proprietary)	VISION
2004-23	12	Massa	**-unknown-** (“ultrasonic sensors”)	X
2004-23	4	SICK	**-unknown-** (“LMS 221”)	LIDAR
2004-23	2	Eaton	**-unknown-** (“Eaton-Vorad radars”)	RADAR
2004-23	2	**-unknown-**	**-unknown-** (“CCD digital color cameras”)	VISION
2004-23	4	**-unknown-**	**-unknown-** (“CCD digital color cameras”)	STEREO

2004-24	1	**-unknown-**	**-unknown-** (LIDAR)	LIDAR
2004-24	(2)	**-unknown-**	**-unknown-** (“road ID cameras”)	VISION
2004-24	1	**-unknown-**	**-unknown-** (“matched set of machine vision cameras”)	STEREO
2004-24	1	Eaton	**-unknown-** (“VORAD radar”)	RADAR
2004-24	**-n-**	**-unknown-**	**-unknown-** (“boundary ID cameras”)	VISION
2004-25	2	Eaton	**-unknown-** (“Eaton VORAD radar”)	RADAR
2004-25	3	SICK	**-unknown-** (LIDAR)	LIDAR
2004-25	1	**-unknown-**	**-unknown-** (“visible light camera”)	VISION

Table XXVI. Navigation sensors in use by 2004 QID and GCE participants.			
Team	**Number**	**Manufacturer**	**Model number**
2004-01	1	Trimble	AgGPS 114
2004-01	(4)	**-unknown-**	**-unknown-** (“individual wheel speed”)
2004-01	**-n-**	**-unknown-**	**-unknown-** (“3-axis accelerometer”)
2004-01	**-n-**	**-unknown-**	**-unknown-** (“3-axis rate gyroscope”)
2004-01	1	**-unknown-**	**-unknown-** (“compass”, “digital compass”, and “electronic compass”)
2004-02	1	AGNC	Land Navigator
2004-03	1	**-unknown-**	**-unknown-** (DGPS)
2004-03	(2)	**-unknown-**	**-unknown-** (AOEs, “wheel rotational positions”)
2004-03	1	Crossbow	**-unknown-** (“VG400”)
2004-03	1	Crossbow	**-unknown-** (“AHRS400”)
2004-03	1	Crossbow	**-unknown-** (IMU)
2004-04	1	Garmin	**-unknown-** (“WAAS GPS”)
2004-04	1	NavCom	**-unknown-** (“Starfire 2050”)
2004-04	1	**-unknown-**	**-unknown-** (“quadrature shaft encoder”, “position and velocity data”)
2004-04	1	OEM	“OEM anti-lock brake speed sensors” (“ground speed”)
2004-04	1	Smiths Aerospace	North Finding Module
2004-05	**-n-**	**-unknown-**	**-unknown-** (“...multiple [DGPS] receivers...”)
2004-05	1	CSI Wireless	Vector
2004-05	1	CSI Wireless	DGPS MAX
2004-05	1	**-unknown-**	**-unknown-** (two-axis inclinometer, “operating plane (tilt measurement) of the vehicle”)

2004-05	1	**-unknown-**	**-unknown-** (“gyroscope”)
2004-05	1	**-unknown-**	**-unknown-** (“gyroscope”)
2004-05	2	**-unknown-**	**-unknown-** (“accelerometer”)
2004-05	4	**-unknown-**	**-unknown-** (“rotary wheel-speed sensors”, “dead reckoning”)
2004-05	1	**-unknown-**	**-unknown-** (“compass”, “digital compass”, and “electronic compass”)
2004-06	1	NavCom	SF-2050G
2004-06	6	Analog Devices	ADXRS150
2004-06	(1)	Honeywell	HMC1002
2004-06	4	Analog Devices	ADXL203
2004-07	1	Garmin	GPS V
2004-07	1	Trimble	AgGPS 114
2004-07	1	Rotomotion	**-unknown-** (“magnetometer”)
2004-07	1	**-unknown-**	**-unknown-** (Hall Effect sensor, “velocity” by “rotation of the rear axle”)
2004-07	1	Rotomotion	**-unknown-** (IMU)
2004-08	1	Applanix	**-unknown-** (“POS LV”)
2004-09	1	MiTAC	Ashtech DG16
2004-09	1	MiTAC	NavmanTU60-D120
2004-09	1	Garmin	16A
2004-09	(4)	**-unknown-**	**-unknown-** (“wheel rotation speed”)
2004-09	(1)	**-unknown-**	**-unknown-** (“ground speed”)
2004-09	(1)	**-unknown-**	**-unknown-** (“current direction”)
2004-09	(1)	**-unknown-**	**-unknown-** (“vehicle attitude with respect to the horizon”)
2004-09	(1)	**-unknown-**	**-unknown-** (“3-axis acceleration”)

2004-09	1	**-unknown-**	**-unknown-** (“gyroscope”)
2004-10	1	Applanix	**-unknown-** (“POS-LV”)
2004-10	(1)	**-unknown-**	**-unknown-** (“vehicle pose (roll, pitch, yaw)”)
2004-10	(1)	**-unknown-**	**-unknown-** (“vehicle velocity”)
2004-11	1	MiTAC	A12
2004-11	1	CSI Wireless	**-unknown-** (“differential beacon receiver”)
2004-11	1	**-unknown-**	**-unknown-** (“standard industrial laser rangefinder”, “pitch and roll relative to the ground”)
2004-11	1	**-unknown-**	**-unknown-** (OE, “ground speed”)
2004-11	1	**-unknown-**	**-unknown-** (“solid-state magnetic compass module”)
2004-12	1	Trimble	AgGPS 114
2004-12	2	Analog Devices	ADXL311
2004-12	1	Omron	E2E-CR8B1
2004-13	1	Rockwell Collins	GNP-10
2004-13	1	NavCom	SF-2050G
2004-13	1	**-unknown-**	**-unknown-** (“digital compass”)
2004-13	1	**-unknown-**	**-unknown-** (Hall Effect sensor, “incremental distance” and “speed”)
2004-14	1	Rockwell Collins	GNP-10
2004-14	1	NavCom	SF-2050G
2004-14	1	**-unknown-**	**-unknown-** (Hall Effect sensor, “incremental distance” and “speed”)
2004-14	1	**-unknown-**	**-unknown-** (“magnetometer”)
2004-15	1	Trimble	AgGPS 114
2004-15	4	**-unknown-**	**-unknown-** (“wheel encoders”, “distance traveled”)
2004-15	1	**-unknown-**	**-unknown-** (“accelerometer”)

2004-15	1	KVH	Azimuth 1000
2004-16	1	C&C Technologies	**-unknown-** (“C-Nav”)
2004-16	1	**-unknown-**	**-unknown-** (INS)
2004-16	**-n-**	**-unknown-**	**-unknown-** (“solar sensors”)
2004-16	1	**-unknown-**	**-unknown-** (“compass”, “digital compass”, and “electronic compass”)
2004-17	1	NavCom	SF-2050G
2004-17	1	PNI	TCM2-50
2004-17	1	Northrop Grumman	LN-200
2004-18	1	NovAtel	ProPak-LBplus
2004-18	1	ISI	**-unknown-** (“RRS75”)
2004-18	1	**-unknown-**	**-unknown-** (“magnetic compass”)
2004-19	1	Trimble	AgGPS 122
2004-19	2	Electro Switch	**-unknown-** (“900 Series” OE, “speed of each [rear] wheel”)
2004-19	1	PNI	Vector 2X
2004-20	1	NovAtel	ProPak-LBplus
2004-20	1	DICKEY-john	**-unknown-** (“doppler radar speedometer”, “vehicle speed relative to the ground”)
2004-20	1	Crossbow	**-unknown-** (“AHRS inertial system”)
2004-20	1	**-unknown-**	**-unknown-** (“magnetic compass”)
2004-21	1	Garmin	GPS V
2004-22	1	NovAtel	ProPak-LBplus
2004-22	1	u-blox	**-unknown-** (GPS)
2004-22	1	**-unknown-**	**-unknown-** (“1-axis gyroscope”)
2004-22	1	Microstrain	**-unknown-** (“3-axis gyroscope”)

2004-22	1	Honeywell	**-unknown-** (“pressure transducer”, “altitude”)
2004-22	4	**-unknown-**	**-unknown-** (“Hall-State proximity sensors”)
2004-23	2	NovAtel	ProPak-LBplus
2004-23	6	**-unknown-**	**-unknown-** (“individual wheel speed”)
2004-23	1	Honeywell	HMR3000
2004-23	1	**-unknown-**	**-unknown-** (IMU)
2004-24	1	NavCom	**-unknown-** (GPS)
2004-24	6	2004-24	custom (“motor/wheel speed”)
2004-24	1	Northrop Grumman	LN-200
2004-24	3	**-unknown-**	**-unknown-** (“magnetometers”, “Coarse Heading Sensor”)
2004-24	3	**-unknown-**	**-unknown-** (“gyros”, “Coarse Heading Sensor”)
2004-24	3	**-unknown-**	**-unknown-** (“accelerometers”, “Coarse Heading Sensor”)
2004-25	1	Honeywell	**-unknown-** (“TALIN integrated DGPS/INS system”)
2004-25	1	**-unknown-**	**-unknown-** (“wheel encoder”, “wheel velocity”)

Table XXVII. Environment sensors in use by 2005 GCE participants.				
Team	**Number**	**Manufacturer**	**Model number**	**Sensor Type**
2005-01	1	AVT	**-unknown-** (“Dolphin”)	VISION
2005-01	1	FLIR	A20M	VISION
2005-01	5	Point Grey	Bumblebee	STEREO
2005-01	1	Eaton	**-unknown-** (“Eaton VORAD RADAR”)	RADAR
2005-01	1	Amphitech	OASys	RADAR
2005-01	**-n-**	**-unknown-**	**-unknown-**	RADAR
2005-01	1	SICK	LMS 211-30206	LIDAR
2005-01	3	SICK	**-unknown-** (“SICK 291 LADAR”)	LIDAR
2005-02	3	SICK	LMS 291-S05	LIDAR
2005-02	1	**-unknown-**	**-unknown-** (“color camera”)	VISION
2005-03	1	2005-03	Digital Auto Drive (DAD)	LIDAR
2005-04	4	SICK	LMS 221-30206	LIDAR
2005-04	1	Eaton	EVT-300	RADAR
2005-04	1	2005-04	**-unknown-** (“second radar”)	RADAR
2005-04	1	**-unknown-**	**-unknown-** (“stereo camera system”)	STEREO
2005-04	8	**-unknown-**	**-unknown-** (“ultrasonic rangefinders”)	X
2005-05	4	SICK	**-unknown-** (“LMS 291”)	LIDAR
2005-05	1	SICK	**-unknown-** (“LMS 221”)	LIDAR
2005-05	1	Mobileye	ACP5	VISION
2005-06	2	SICK	**-unknown-** (“LMS 291”)	LIDAR

2005-07	2	SICK	**-unknown-** (LIDAR)	LIDAR
2005-07	**-n-**	**-unknown-**	**-unknown-** (“stereo cameras”)	STEREO
2005-08	2	Riegl	LMS-Q120	LIDAR
2005-08	1	SICK	LMS 291-S14	LIDAR
2005-08	1	SICK	LMS 211-30106	LIDAR
2005-08	3	Delphi	Forewarn ACC3	RADAR
2005-08	1	Delphi	Dual-beam RADAR Back-Up Aid (BUA)	X
2005-08	4	**-unknown-**	**-unknown-** (“ultrasonic sensors”)	X
2005-08	2	Sony	DFW-VL500	STEREO
2005-08	2	**-unknown-**	**-unknown-** (“road following” cameras)	VISION
2005-08	1	**-unknown-**	**-unknown-** (“active bumper”)	X
2005-09	8	SICK	**-unknown-** (“laser range finders”)	LIDAR
2005-10	2	SICK	**-unknown-** (“LMS-291”)	LIDAR
2005-10	2	Cognex	DVT 542C	VISION
2005-10	1	**-unknown-**	**-unknown-** (“stereo camera”)	STEREO
2005-10	1	Optech	ILRIS-3D	LIDAR
2005-11	**-n-**	SICK	**-unknown-** (“LMS 291”)	LIDAR
2005-12	1	Point Grey	Bumblebee	STEREO
2005-13	1	Riegl	LMS-Q140i	LIDAR
2005-13	4	SICK	**-unknown-** (“LMS 291”)	LIDAR
2005-13	1	Navtech	DS2000	RADAR
2005-14	1	Riegl	LMS-Q140i	LIDAR
2005-14	4	SICK	**-unknown-** (“LMS 291”)	LIDAR

2005-14	1	Navtech	DS2000	RADAR
2005-15	4	SICK	**-unknown-** (“LMS-221”)	LIDAR
2005-15	1	2005-15	Stereo Vision System (SVS)	STEREO
2005-16	5	SICK	**-unknown-** (“laser range finders”)	LIDAR
2005-16	1	**-unknown-**	**-unknown-** (“color camera”)	VISION
2005-17	2	SICK	**-unknown-** (“LMS 291”)	LIDAR
2005-18	2	SICK	LMS 221-30206	LIDAR
2005-18	1	SICK	LMS 291-S14	LIDAR
2005-18	1	SICK	LMS 291-S05	LIDAR
2005-18	1	Riegl	LMS-Q120i	LIDAR
2005-18	4	Point Grey	Dragonfly (“Stereovision” cameras)	STEREO
2005-18	1	Point Grey	Dragonfly (“Road-finding camera”)	VISION
2005-19	3	SICK	**-unknown-** (“LMS 291”)	LIDAR
2005-20	**-n-**	**-unknown-**	**-unknown-** (LIDAR)	LIDAR
2005-20	**-n-**	**-unknown-**	**-unknown-** (“millimeter wave RADAR”)	RADAR
2005-20	**-n-**	**-unknown-**	**-unknown-** (“stereo camera”)	STEREO
2005-21	2	SICK	**-unknown-** (“LMS-291”)	LIDAR
2005-21	1	Ibeo	**-unknown-** (“ALASCA”)	LIDAR
2005-21	3	**-unknown-**	**-unknown-** (“trinocular camera system”)	STEREO
2005-22	1	SICK	**-unknown-** (“LMS-291”)	LIDAR
2005-22	1	Point Grey	Bumblebee	VISION
2005-23	3	SICK	**-unknown-** (“LMS-291”)	LIDAR
2005-23	1	Point Grey	Bumblebee	VISION

Table XXVIII. Navigation sensors in use by 2005 GCE participants.			
Team	**Number**	**Manufacturer**	**Model number**
2005-01	2	NavCom	SF-2050G
2005-01	1	Northrop Grumman	LN-270
2005-02	1	Smiths Aerospace	North Finding Module
2005-02	1	Garmin	16
2005-02	1	NavCom	**-unknown-** (“Starfire 2050”)
2005-03	1	NavCom	SF-2050G
2005-03	1	NovAtel	ProPak-LBplus
2005-03	1	KVH	DSP-5000
2005-03	1	**-unknown-**	**-unknown-** (“6-axis inertial system”)
2005-03	1	OEM	vehicle odometer
2005-04	1	NovAtel	ProPak-LBplus
2005-04	1	Crossbow	VG700AA-201
2005-04	(6)	**-unknown-**	**-unknown-** (“wheel speed sensors”)
2005-05	1	NovAtel	ProPak-LBplus
2005-05	1	Systron Donner	C-MIGITS III
2005-05	1	**-unknown-**	**-unknown-** (Hall Effect sensor, “odometry”)
2005-06	1	Oxford	RT3000
2005-06	1	**-unknown-**	**-unknown-** (“wheel speed sensor”)
2005-07	(1)	**-unknown-**	**-unknown-** (GPS)
2005-08	1	Honeywell	TALIN-5000

2005-08	1	NovAtel	ProPak-LBplus
2005-08	1	Vansco	**-unknown-** ("Doppler radar sensor")
2005-09	2	Trimble	AgGPS 132
2005-09	1	Microbotics	MIDG-II
2005-09	1	**-unknown-**	**-unknown-** ("quadrature shaft encoder", "vehicle displacement")
2005-09	1	**-unknown-**	**-unknown-** ("encoder", "steering wheel angle")
2005-10	1	NavCom	SF-2050G
2005-10	1	Garmin	GPSMAP 76CS
2005-10	1	Kearfott	**-unknown-** ("MIL-NAV")
2005-10	1	Crossbow	**-unknown-** ("3 axis accelerometer")
2005-10	1	PNI	TCM2
2005-11	1	Crossbow	**-unknown-** ("Navigation Attitude Heading Reference System (NAHRS) module")
2005-11	1	NovAtel	**-unknown-** (GPS)
2005-11	**-n-**	**-unknown-**	**-unknown-** ("wheel speed sensors", "odometry data")
2005-12	1	Trimble	**-unknown-** (GPS)
2005-12	1	**-unknown-**	**-unknown-** ("optical rotary encoder", "precise position feedback")
2005-13	1	Applanix	**-unknown-** ("POS LV")
2005-13	1	Trimble	AgGPS 252
2005-14	1	Applanix	**-unknown-** ("POS LV")
2005-14	1	Trimble	AgGPS 252
2005-15	1	NavCom	**-unknown-** ("Starfire")
2005-15	1	Rockwell Collins	**-unknown-** ("GIC-100")
2005-15	1	PNI	TCM2

2005-15	1	Microstrain	3DM-GX1
2005-15	1	OEM	“speedometer encoder” (“speed data”)
2005-16	1	**-unknown-**	**-unknown-** (“GPS positioning system”)
2005-16	1	**-unknown-**	**-unknown-** (“GPS compass”)
2005-16	1	**-unknown-**	**-unknown-** (“six degree-of-freedom IMU”)
2005-17	1	Oxford	RT3102
2005-17	1	C&C Technologies	**-unknown-** (“C-Nav”)
2005-18	1	NavCom	SF-2050G
2005-18	1	NovAtel	DL-4plus
2005-18	1	Northrop Grumman	LN-200
2005-19	1	Trimble	AgGPS 252
2005-19	1	Northrop Grumman	LN-200
2005-19	1	**-unknown-**	**-unknown-**
2005-20	2	NovAtel	ProPak-LBplus
2005-20	1	NovAtel	HG1700 SPAN
2005-21	2	Oxford	RT3100
2005-21	1	Trimble	AgGPS 132
2005-21	1	**-unknown-**	**-unknown-** (“wheel speed sensor”, “sensed wheel speed”)
2005-21	1	**-unknown-**	**-unknown-** (“encoder”, “wheel angle”)
2005-22	1	NovAtel	ProPak-LBplus
2005-22	1	NovAtel	HG1700 SPAN
2005-22	1	**-unknown-**	**-unknown-** (“throttle” encoder)
2005-22	1	**-unknown-**	**-unknown-** (“steering” encoder)

2005-23	1	NovAtel	ProPak-LBplus
2005-23	1	NovAtel	HG1700 SPAN
2005-23	1	**-unknown-**	**-unknown-** (“throttle” encoder)
2005-23	1	**-unknown-**	**-unknown-** (“steering” encoder)

Table XXIX. Known sensors by quantity (2004 QID and GCE participants).												
Team	**State**				**Environment**				**Navigation**			
	Total	**K**	**U**	**E**	**Total**	**K**	**U**	**E**	**Total**	**K**	**U**	**E**
2004-10	5		5		2	2			3	1		2
2004-14	4	1		3	7	3	3	1	4	4		
2004-06					1	1			4	3		1
2004-07	1	1			5	5			5	5		
2004-17	1	1			3	3			3	3		
2004-23	3			3	4	4			4	4		
2004-13	4	1		3	6	4	1	1	4	4		
2004-04	5	4	1		6	6			5	5		
2004-18	5		1	4	3	3			3	3		
2004-02	2	1	1		6	5		1	1	1		
2004-09	2			2	3	3			9	4		5
2004-16					4	2	2		4	3	1	
2004-25	5	4	1		3	3			2	2		
2004-03	2			2	3	3			5	4		1
2004-24	8	3		5	5	3	1	1	6	6		
GCE	47	16	9	22	61	50	7	4	62	52	1	9
2004-01	9			9	4	3	1		5	2	2	1
2004-05	9	8	1		7	7			9	8	1	
2004-08	3	3			3	3			1	1		
2004-11	1	1			4	4			5	5		
2004-12	2	2			2	2			3	3		
2004-15	8			8	4	3	1		4	4		
2004-19					3	3			3	3		
2004-20	5		3	2	5	3	2		4	4		
2004-21	4		3	1	2	2			1	1		
2004-22	2	1		1	1	1			6	6		
QID	90	31	16	43	96	81	11	4	103	89	4	10

Table XXX. Known sensors by manufacturer (2004 QID and GCE participants).									
Team	**State**			**Environment**			**Navigation**		
	Total	**K**	**U**	**Total**	**K**	**U**	**Total**	**K**	**U**
2004-10	5		5	2	2		3	1	2
2004-14	4		4	7	3	4	4	2	2
2004-06				1	1		4	4	
2004-07	1		1	5	4	1	5	4	1
2004-17	1	1		3	3		3	3	
2004-23	3		3	4	3	1	4	2	2
2004-13	4		4	6	3	3	4	2	2
2004-04	5	5		6	4	2	5	4	1
2004-18	5		5	3	1	2	3	2	1
2004-02	2	1	1	6	6		1	1	
2004-09	2		2	3	1	2	9	3	6
2004-16				4	1	3	4	1	3
2004-25	5	2	3	3	2	1	2	1	1
2004-03	2		2	3	2	1	5	3	2
2004-24	8		8	5	1	4	6	3	3
GCE	47	9	38	61	37	24	62	36	26
2004-01	9		9	4	1	3	5	1	4
2004-05	9		9	7	3	4	9	2	7
2004-08	3	1	2	3	3		1	1	
2004-11	1		1	4	2	2	5	2	3
2004-12	2	2		2	1	1	3	3	
2004-15	8		8	4	3	1	4	2	2
2004-19				3	1	2	3	3	
2004-20	5		5	5	3	2	4	3	1
2004-21	4		4	2	2		1	1	
2004-22	2	1	1	1	1		6	4	2
QID	90	13	77	96	57	39	103	58	45

Table XXXI. Known sensors by manufacturer and model number (2004 QID and GCE participants).									
Team	**State**			**Environment**			**Navigation**		
	Total	**K**	**U**	**Total**	**K**	**U**	**Total**	**K**	**U**
2004-10				2	1	1	1		1
2004-14				3		3	2	2	
2004-06				1	1		4	4	
2004-07				4	3	1	4	2	2
2004-17	1	1		3	3		3	3	
2004-23				3		3	2	2	
2004-13				3		3	2	2	
2004-04	5	5		4	2	2	4	2	2
2004-18				1	1		2	1	1
2004-02	1	1		6	5	1	1	1	
2004-09				1		1	3	3	
2004-16				1		1	1		1
2004-25	2	2		2		2	1		1
2004-03				2	1	1	3		3
2004-24				1		1	3	2	1
GCE	9	9		37	17	20	36	24	12
2004-01				1		1	1	1	
2004-05				3	1	2	2	2	
2004-08	1	1		3	3		1		1
2004-11				2	1	1	2	1	1
2004-12	2	2		1	1		3	3	
2004-15				3	3		2	2	
2004-19				1	1		3	2	1
2004-20				3	3		3	1	2
2004-21				2	2		1	1	
2004-22	1		1	1	1		4	1	3
QID	13	12	1	57	33	24	58	38	20

Table XXXII. Known sensors by quantity (2005 GCE participants).												
Team	State				Environment				Navigation			
	Total	K	U	E	Total	K	U	E	Total	K	U	E
2005-16					2	2			3	3		
2005-13					3	3			2	2		
2005-14					3	3			2	2		
2005-06					1	1			2	2		
2005-21					3	3			4	4		
2005-20					3		3		2	2		
2005-01					8	7	1		2	2		
2005-22					2	2			4	4		
2005-23					2	2			4	4		
2005-04					5	5			3	2		1
2005-03					1	1			5	5		
2005-07					2	1	1		1			1
2005-10					4	4			5	5		
2005-05					3	3			3	3		
2005-17					1	1			2	2		
2005-15					2	2			5	5		
2005-08					9	9			3	3		
2005-02					2	2			3	3		
2005-12					1	1			2	2		
2005-19					1	1			3	3		
2005-18					6	6			3	3		
2005-11					1		1		3	2	1	
2005-09					1	1			4	4		
TOTAL					66	60	6		70	67	1	2

Table XXXIII. Known sensors by manufacturer (2005 GCE participants).									
Team	**State**			**Environment**			**Navigation**		
	Total	**K**	**U**	**Total**	**K**	**U**	**Total**	**K**	**U**
2005-16				2	1	1	3		3
2005-13				3	3		2	2	
2005-14				3	3		2	2	
2005-06				1	1		2	1	1
2005-21				3	2	1	4	2	2
2005-20				3		3	2	2	
2005-01				8	7	1	2	2	
2005-22				2	2		4	2	2
2005-23				2	2		4	2	2
2005-04				5	3	2	3	2	1
2005-03				1	1		5	4	1
2005-07				2	1	1	1		1
2005-10				4	3	1	5	5	
2005-05				3	3		3	2	1
2005-17				1	1		2	2	
2005-15				2	2		5	5	
2005-08				9	6	3	3	3	
2005-02				2	1	1	3	3	
2005-12				1	1		2	1	1
2005-19				1	1		3	2	1
2005-18				6	6		3	3	
2005-11				1	1		3	2	1
2005-09				1	1		4	2	2
TOTAL				66	52	14	70	51	19

Table XXXIV. Known sensors by manufacturer and model number (2005 GCE participants).

Team	State			Environment			Navigation		
	Total	K	U	Total	K	U	Total	K	U
2005-01				7	4	3	2	2	
2005-02				1	1		3	2	1
2005-03				1	1		4	4	
2005-04				3	2	1	2	2	
2005-05				3	1	2	2	2	
2005-06				1		1	1	1	
2005-07				1		1			
2005-08				6	6		3	2	1
2005-09				1		1	2	2	
2005-10				3	2	1	5	3	2
2005-11				1		1	2		2
2005-12				1	1		1		1
2005-13				3	2	1	2	1	1
2005-14				3	2	1	2	1	1
2005-15				2	1	1	5	3	2
2005-16				1		1			
2005-17				1		1	2	1	1
2005-18				6	6		3	3	
2005-19				1		1	2	2	
2005-20							2	2	
2005-21				2		2	2	2	
2005-22				2	1	1	2	2	
2005-23				2	1	1	2	2	
TOTAL				52	31	21	51	39	12

Table XXXV. Alphabetical list of acronyms in use throughout this technical report.	
6DOF	Six (6) Degrees-Of-Freedom
AHRS	Attitude and Heading Reference System
AOE	Absolute Optical Encoder
CG	Center of Gravity
COTS	Commercial Off-The-Shelf
CWFM	Continuous Wave Frequency Modulated
DARPA	Defense Advanced Research Projects Agency
DGPS	Differential Global Positioning System
DOD	Department of Defense
DOF	Degrees-Of-Freedom
FMCW	Frequency Modulated Continuous Wave
GCE	Grand Challenge Event
GPS	Global Positioning System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LIDAR	LIght Detection And Ranging
MEMS	Micro-Electrical Mechanical System
NQE	National Qualification Event
OBD	On-Board Diagnostic
OE	Optical Encoder
OEM	Original Equipment Manufacturer
PC	Personal Computer
QID	Qualification, Inspection, and Demonstration
RADAR	RAdio Detection And Ranging
RDDF	Route Data Definition File
SSF	Static Stability Factor
SUV	Sport Utility Vehicle
WAAS	Wide-Area Augmentation System

Table XXXVI. Major obstacle and path detection sensors by type (2004 QID and GCE participants).								
Team	VISION		LIDAR		RADAR		QID	GCE
	Stereo Camera Pair	Other Cameras	Scanning laser range finder	Other LIDAR	Navigation RADAR	Other RADAR		
2004-10			4				Y	7.4
2004-14		**-n-**	4		1		Y	6.7
2004-06	1						Y	6.0
2004-07		3	1		1		Y	5.2
2004-17	2	1	2				Y	1.3
2004-23	2	2	4		2		Y	1.2
2004-13		1	4		1		Y	0.75
2004-04	1	3	2			4	Y	0.45
2004-18	1		1			3	Y	0.20
2004-02	3	2	1		1		Y	0.0
2004-09		1	1				Y	0.0
2004-16		2	2		1		Y	0.0
2004-25		1	3		2		Y	0.0
2004-03		3			1		Y	WD
2004-24	1	2+	1		1		Y	WD
2004-01		2	2				N	–
2004-05	1		2		1		N	–
2004-08		2		5[a]			N	–
2004-11		1	1	1			N	–
2004-12			1				N	–

2004-15			1			1	N	–
2004-19	1			1			N	–
2004-20		1	1		1		N	–
2004-21					1		N	–
2004-22		1					N	–

Note:

[a] Four Laseroptronix LDM 800-RS232 and one Laseroptronix Sea-Lynx LIDAR sensors were in use by Team 2004-08 during the 2004 QID.

Table XXXVII. Major obstacle and path detection sensors by type (2005 GCE participants).							
Team	**VISION**		**LIDAR**		**RADAR**		**GCE[43]**
	Stereo Camera Pair	**Other Cameras**	**Scanning laser range finder**	**Other LIDAR**	**Navigation RADAR**	**Other RADAR**	
2005-16		1	5				131.7
2005-13			5		1		131.7
2005-14			5		1		131.7
2005-06			2				131.7
2005-21	3		3				131.7
2005-20	**-n-**		**-n-**		**-n-**		81.2
2005-01	5	2	4		2+		66.2
2005-22	1		1				43.5
2005-23	1		3				39.4
2005-04	1		4		1+		29.0
2005-03			1				26.2
2005-07	**-n-**		2				25.6
2005-10	1	2	3				23.0
2005-05		1	5				22.4
2005-17			2				17.2
2005-15	1		4				15.9
2005-08	1	2	4			3	14.0
2005-02		1	3				13.6
2005-12	1						9.5
2005-19			3				8.9

2005-18	2	1	5				8.0
2005-11			**-n-**				7.2
2005-09			8				0.7

Table XXXVIII. High-quality obstacle and path detection sensors (2004 QID and GCE participants).					
Team	**STEREO**	**LIDAR**	**RADAR**	**QID**	**GCE**
2004-10		4		Y	7.4
2004-14		4	1	Y	6.7
2004-06				Y	6.0
2004-07		1	1	Y	5.2
2004-17	2	2		Y	1.3
2004-23	2	4	2	Y	1.2
2004-13		4	1	Y	0.75
2004-04	1	2		Y	0.45
2004-18	1	1		Y	0.20
2004-02	3	1	1	Y	0.0
2004-09		1		Y	0.0
2004-16		2	1	Y	0.0
2004-25		3	2	Y	0.0
2004-03			1	Y	WD
2004-24		1	1	Y	WD
2004-01		2		N	–
2004-05	1	2	1	N	–
2004-08				N	–
2004-11		1		N	–
2004-12		1		N	–
2004-15		1		N	–
2004-19				N	–
2004-20		1	1	N	–
2004-21			1	N	–
2004-22				N	–

Table XXXIX. High-quality obstacle and path detection sensors (2005 GCE participants).				
Team	**STEREO**	**LIDAR**	**RADAR**	**GCE**[43]
2005-16		5		131.7
2005-13		5	1	131.7
2005-14		5	1	131.7
2005-06		2		131.7
2005-21	3	3		131.7
2005-20		**-n-**	**-n-**	81.2
2005-01	5	4		66.2
2005-22	1	1		43.5
2005-23	1	3		39.4
2005-04	1	4		29.0
2005-03		1		26.2
2005-07		2		25.6
2005-10		3		23.0
2005-05		5		22.4
2005-17		2		17.2
2005-15	1	4		15.9
2005-08	1	4		14.0
2005-02		3		13.6
2005-12	1			9.5
2005-19		3		8.9
2005-18	2	5		8.0
2005-11		**-n-**		7.2
2005-09		8		0.7

Table XL. Number of teams using high-quality sensors[a].					
2004 GCE			**2005 GCE**		
STEREO	**LIDAR**	**RADAR**	**STEREO**	**LIDAR**	**RADAR**
5/15 (33 percent)	13/15 (87 percent)	9/15 (60 percent)	9/23 (39 percent)	22/23 (96 percent)	3/23 (13 percent)

Note:

[a] The information presented by this table is formatted as follows: number of teams using this type of high-quality sensor / number of teams participating in the 2004 or 2005 GCE (percent of teams using this type of high-quality sensor).

Table XLI. Number of high-quality sensors in use[a].					
2004 GCE			**2005 GCE**		
STEREO	**LIDAR**	**RADAR**	**STEREO**	**LIDAR[b]**	**RADAR[c]**
9/5 (1.8)	30/13 (2.3)	11/9 (1.2)	16/9 (1.8)	72/20 (3.6)	2/2 (1.0)

Notes:

[a] The information presented by this table is formatted as follows: number of high-quality sensors of this type in use by teams participating in the 2004 or 2005 GCE / number of teams using this type of high-quality sensor (average number of high-quality sensors of this type in use by each team).

[b] An unknown number of high-quality LIDAR sensors were in use by Teams 2005-11 and 2005-20. See paragraphs VI.B.3.a., V.C.36.a., and V.C.44.a.

[c] An unknown number of high-quality RADAR sensors were in use by Team 2005-20. See paragraphs VI.B.2.a. and V.C.44.b.

Table XLII. Number of high-quality sensors in use by teams which participated in both the 2004 and 2005 GCE.

Team	STEREO	LIDAR	RADAR	Team	STEREO	LIDAR	RADAR
2004-02	3	1	1	2005-01	5	4	
2004-04	1	2		2005-02		3	
2004-06				2005-03		1	
2004-07		1	1	2005-05		5	
2004-08				2005-07		2	
2004-10		4		2005-13		5	1
2004-13		4	1	2005-15	1	4	
2004-16		2	1	2005-17		2	
2004-17	2	2		2005-18	2	5	
2004-18	1	1		2005-20		**-n-**	**-n-**
2004-23	2	4	2	2005-21	3	3	
2004-25		3	2	2005-22	1	1	

Table XLIII. Number of SICK LMS LIDAR sensors in use by teams which participated in the 2004 and 2005 GCE.

LMS	2004	2005
200	2	
211	1	2
220	1	
221	6	11
291		36[a]
Unknown	18	15
TOTAL	28	64

Note:

[a] An unknown number of high-quality LIDAR sensors were in use by Teams 2005-11 and 2005-20. See paragraphs VI.B.3.a., V.C.36.a., and V.C.44.a.

Table XLIV. Navigation sensor integration (2004 QID and GCE participants).						
Team	**COTS Integration**		**Team Integration**		**QID**	**GCE**
	Kalman	**Other**	**Kalman**	**Other**		
2004-10	X				Y	7.4
2004-14			X		Y	6.7
2004-06				X	Y	6.0
2004-07				X	Y	5.2
2004-17				X	Y	1.3
2004-23				X	Y	1.2
2004-13			X		Y	0.75
2004-04	X				Y	0.45
2004-18			X		Y	0.20
2004-02		X			Y	0.0
2004-09				X	Y	0.0
2004-16			X		Y	0.0
2004-25	X				Y	0.0
2004-03	X				Y	WD
2004-24			X		Y	WD
2004-01				X	N	–
2004-05				X	N	–
2004-08	X				N	–
2004-11				X	N	–
2004-12				X	N	–
2004-15			X		N	–
2004-19				X	N	–
2004-20	X				N	–
2004-21[a]					N	–
2004-22	X				N	–

Notes:

[a] GPS only was in use by Team 2004-21. See paragraph VII.B.

Table XLV. Navigation sensor integration (2005 GCE participants).					
Team[a]	COTS Integration		Team Integration		GCE[43]
	Kalman	Other	Kalman	Other	
2005-16			X		131.7
2005-13	X				131.7
2005-14	X				131.7
2005-06	X				131.7
2005-21	X				131.7
2005-20		X			81.2
2005-01		X			66.2
2005-22		X			43.5
2005-23		X			39.4
2005-04			X		29.0
2005-03				X	26.2
2005-07				X	25.6
2005-10	X				23.0
2005-05	X				22.4
2005-17	X				17.2
2005-15			X		15.9
2005-08	X				14.0
2005-02	X				13.6
2005-12			X		9.5
2005-19			X		8.9
2005-18			X		8.0
2005-11	X				7.2
2005-09				X	0.7

Note:

[a] Teams are in decreasing order of number of miles of the 2005 GCE course completed. Grey shading denotes teams which completed less than 25 percent of the 2005 GCE course (32.9 miles).

Table XLVI. Navigation sensor integration strategies and Kalman filter usage by teams which participated in both the 2004 and 2005 GCE.

Team[a]	COTS Integration		Team Integration		Team	COTS Integration		Team Integration	
	K[b]	O[c]	K	O		K	O	K	O
2004-10	X				2005-13	X			
2004-23				X	2005-21	X			
2004-18			X		2005-20		X		
2004-02		X			2005-01		X		
2004-25	X				2005-22		X		
2004-06				X	2005-03				X
2004-08	X				2005-07				X
2004-07				X	2005-05	X			
2004-16			X		2005-17	X			
2004-13			X		2005-15			X	
2004-04	X				2005-02	X			
2004-17				X	2005-18			X	

Notes:

[a] Teams are in decreasing order of number of miles of the 2005 GCE course completed. Grey shading denotes teams which completed less than 25 percent of the 2005 GCE course (32.9 miles).

[b] "K" denotes use of a Kalman filter to integrate navigation sensors.

[c] "O" denotes independent implementation of an other sensor fusion strategy.

Table XLVII. Navigation sensor integration strategies in use by teams which participated in the 2004 or 2005 GCE.		
	COTS Integration	**Team Integration**
2004 (15 teams)	5 (33.3 percent)	10 (66.7 percent)
2005 (23 teams)	14 (60.9 percent)	9 (39.1 percent)

Table XLVIII. Kalman filter usage by teams which participated in the 2004 or 2005 GCE.	
2004 (15 teams)	9 (60.0 percent)
2005 (23 teams)	16 (69.6 percent)

Table XLIX. COTS integration using a Kalman filter by teams which participated in the 2004 or 2005 GCE.	
2004 (15 teams)	4 (26.6 percent)
2005 (23 teams)	10 (43.5 percent)

Table L. Navigation sensor integration strategies in use by teams which participated in both the 2004 and 2005 GCE.		
	COTS Integration	**Team Integration**
2004	5 (41.7 percent)	7 (58.3 percent)
2005	8 (66.7 percent)	4 (33.3 percent)

Table LI. Kalman filter usage by teams which participated in both the 2004 and 2005 GCE.	
2004	7 (58.3 percent)
2005	7 (58.3 percent)

Table LII. COTS integration using a Kalman filter by teams which participated in both the 2004 and 2005 GCE.	
2004	4 (33.3 percent)
2005	5 (41.7 percent)

Table LIII. Stopping distance for selected values of v and μ_k.												
v, mph	**Stopping distance (d_s), m (ft), for μ_k =**											
	0.1	**0.2**	**0.3**	**0.33**	**0.4**	**0.5**	**0.6**	**0.65**	**0.7**	**0.73**	**0.8**	**0.9**
5	2.6 (8.4)	1.3 (4.2)	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
10	10.2 (33.4)	5.1 (16.7)	3.4 (11.1)	3.1 (10.1)	2.6 (8.4)	2.0 (6.7)	1.7 (5.6)	1.6 (5.1)	1.5 (4.8)	1.4 (4.6)	1.3 (4.2)	1.1 (3.7)
15	22.9 (75.2)	11.5 (37.6)	7.7 (25.1)	6.9 (22.8)	5.7 (18.8)	4.6 (15.0)	3.8 (12.5)	3.5 (11.6)	3.3 (10.7)	3.2 (10.4)	2.9 (9.4)	2.6 (8.4)
20	40.7 (133.6)	20.4 (66.8)	13.6 (44.5)	12.3 (40.5)	10.2 (33.4)	8.1 (26.7)	6.8 (22.3)	6.3 (20.6)	5.8 (19.1)	5.6 (18.4)	5.1 (16.7)	4.5 (14.8)
25	63.6 (208.8)	31.8 (104.4)	21.2 (69.6)	19.3 (63.3)	15.9 (52.2)	12.7 (41.8)	10.6 (34.8)	9.8 (32.1)	9.1 (29.8)	8.8 (28.8)	8.0 (26.1)	7.1 (23.2)
30	91.6 (300.6)	45.8 (150.3)	30.5 (100.2)	27.8 (91.1)	22.9 (75.2)	18.3 (60.1)	15.3 (50.1)	14.1 (46.2)	13.1 (42.9)	12.6 (41.5)	11.5 (37.6)	10.2 (33.4)
35	124.7 (409.2)	62.4 (204.6)	41.6 (136.4)	37.8 (124.0)	31.2 (102.3)	24.9 (81.8)	20.8 (68.2)	19.2 (63.0)	17.8 (58.5)	17.2 (56.4)	15.6 (51.1)	13.9 (45.5)
40	162.9 (534.4)	81.4 (267.2)	54.3 (178.1)	49.4 (162.0)	40.7 (133.6)	32.6 (106.9)	27.2 (89.1)	25.1 (82.2)	23.3 (76.3)	22.5 (73.7)	20.4 (66.8)	18.1 (59.4)
45	206.2 (676.4)	103.1 (338.2)	68.7 (225.5)	62.5 (205.0)	51.5 (169.1)	41.2 (135.3)	34.4 (112.7)	31.7 (104.1)	29.4 (96.6)	28.4 (93.3)	25.8 (84.5)	22.9 (75.2)
50	254.5 (835.1)	127.3 (417.5)	84.9 (278.4)	77.1 (253.0)	63.6 (208.8)	50.9 (167.0)	42.4 (139.2)	39.2 (128.5)	36.4 (119.3)	35.1 (115.2)	31.8 (104.4)	28.3 (92.8)
55	[b]	154.0 (505.2)	102.7 (336.8)	93.3 (306.2)	77.0 (252.6)	61.6 (202.1)	51.3 (168.4)	47.4 (155.4)	44.0 (144.3)	42.5 (139.4)	38.5 (126.3)	34.2 (112.3)
60	[b]	183.2 (601.2)	122.2 (400.8)	111.1 (364.4)	91.6 (300.6)	73.3 (240.5)	61.1 (200.4)	56.4 (185.0)	52.4 (171.8)	50.6 (165.9)	45.8 (150.3)	40.7 (133.6)

Notes:

[a] Stopping distance is less than 1.0 m (3.3 ft).

[b] Stopping distance is greater than 304.8 m (1000.0 ft).

Table LIV. Maximum distance between the path of travel in a constant-radius turn and the left- or right-limit of field-of-view of various RADAR systems.

Turn radius, ft	Maximum distance, d, ft / in		
	Eaton EVT-300 ($\alpha = \pm 6$ degrees)	Epsilon Lambda ELSC71-1A	
		Narrow-scan mode ($\alpha = \pm 8$ degrees)	Wide-scan mode ($\alpha = \pm 20$ degrees)
10	0.05 / 0.6	0.10 / 1.2	0.60 / 7.2
20	0.11 / 1.3	0.19 / 2.3	1.21 / 14.5
30	0.16 / 1.9	0.29 / 3.5	1.81 / 21.7
40	0.22 / 2.6	0.39 / 4.7	2.41 / 28.9
50	0.27 / 3.2	0.49 / 5.9	3.02 / 36.2
60	0.33 / 4.0	0.58 / 7.0	3.62 / 43.4
70	0.38 / 4.6	0.68 / 8.2	4.22 / 50.6
80	0.44 / 5.3	0.78 / 9.4	4.82 / 57.8

Table LV. Comparison of stopping distance to maximum obstacle detection range for VISION, STEREO, LIDAR, and RADAR sensors (2004 QID and GCE participants).						
Team	**Speed, mph**	**Stopping distance, m**	**Sensor**	**Maximum obstacle detection range, m**	**Exceeded**	**Range ratio**
2004-01	45	62.5	Unknown cameras	45.7	Y	1.37
			Unknown SICK LIDAR sensors	61.0	Y	1.02
2004-02	50	77.1	SICK LMS 211-30206	30.0	Y	2.57
			Point Grey Bumblebee stereo camera pairs	50.0	Y	1.54
			FLIR A20M camera	50.0	Y	1.54
			Unknown AVT cameras	50.0	Y	1.54
			Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	Y	2.57
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	110.0	N	0.70
2004-03	25	19.3	Unknown Cognex cameras	100.0	N	0.19
			Unknown other camera	100.0	N	0.19
			Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	N	0.64
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	40.0	N	0.48
2004-04	50	77.1	Unknown Videre Design stereo camera pair	[a]	N/A	N/A
			Unknown other cameras	[a]	N/A	N/A
			Unknown long-range RADAR	30.5	Y	2.53
			SICK LMS 200-30106	30.0	Y	2.57
2004-05	55	93.3	Unknown SICK LIDAR sensors	45.7	Y	2.04
			Unknown Eaton RADAR	91.4	Y	1.02
			Point Grey Bumblebee stereo camera pair	[a]	N/A	N/A

2004-06	60	111.1	Proprietary stereo camera pair	91.4	Y	1.22
2004-07	45	62.5	Unknown SICK LIDAR sensor	10.0	Y	6.25
			Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	Y	2.08
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	40.0	Y	1.56
			FLIR Omega camera	[a]	N/A	N/A
			Sony DFW-VL500 cameras	[a]	N/A	N/A
2004-08	55	93.3	Laseroptronix LDM 800-RS232	400.0	N	0.23
			Laseroptronix Sea-Lynx	350.0	N	0.27
			Cohu 1330 cameras	100.0	N	0.93
2004-09	60	111.1	Unknown SICK LIDAR sensor	15.2	Y	7.31
			Unknown camera	12.2	Y	9.11
2004-10	36	40.0	Unknown SICK LIDAR sensors	25.0	Y	1.60
			Riegl LMS-Q140i	75.0	N	0.53
2004-11	60	111.1	Unknown long-range laser ranger	152.4	N	0.73
			Unknown scanning laser range finder	61.0	Y	1.82
			Unknown Omnivision sensor	[a]	N/A	N/A
2004-12	40	49.4	SICK LMS 291-S05	50.0	N	0.99
2004-13	60	111.1	Unknown SICK LIDAR sensors	80.0	Y	1.39
			Unknown camera	100.0	Y	1.11
			Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	Y	3.70
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	110.0	Y	1.01
2004-14	40	49.4	Unknown cameras	100.0	N	0.49
			Unknown SICK LIDAR sensors	80.0	N	0.62

			Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	Y	1.65
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	110.0	N	0.45
2004-15	50	77.1	SICK LMS 211-30206	80.0	N	0.96
			Eaton EVT-300 RADAR	100.0	N	0.77
2004-16	30	27.8	Unknown cameras	90.0	N	0.31
			Unknown RADAR	100.0	N	0.28
			Unknown SICK LIDAR sensors	100.0	N	0.28
2004-17	40	49.4	Point Grey Dragonfly stereo camera pair	30.0	Y	1.65
			SICK LMS 221-30206	30.0	Y	1.65
2004-18	60	111.1	Unknown RADAR	304.8	N	0.36
			SICK LMS 220-30106	30.5	Y	3.64
			Unknown stereo camera pair	91.4	Y	1.22
2004-19	30	27.8	Unknown stereo camera pair	[a]	N/A	N/A
			SICK DME 2000	10.7	Y	2.60
2004-20	40	49.4	SICK LMS 221-30206	45.0	Y	1.10
			Eaton EVT-300 RADAR	50.0	N	0.99
			Unibrain Fire-i 400 camera	[a]	N/A	N/A
2004-21	60	111.1	Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	30.0	Y	3.70
			Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	110.0	Y	1.01
2004-22	60	111.1	Proprietary video system	243.8	N	0.46
2004-23	50	77.1	Unknown SICK LIDAR sensors	40.0	Y	1.93
			Unknown Eaton RADAR sensors	150.0	N	0.51
			Unknown cameras	75.0	Y	1.03

2004-24	25	19.3	Unknown cameras	[a]	N/A	N/A
			Unknown LIDAR sensor	[a]	N/A	N/A
			Unknown Eaton RADAR	[a]	N/A	N/A
2004-25	35	37.8	Unknown camera	[a]	N/A	N/A
			Unknown SICK LIDAR sensors	[a]	N/A	N/A
			Unknown Eaton RADAR	[a]	N/A	N/A

Note:

[a] Maximum obstacle detection range for this sensor was not reported.

Table LVI. Comparison of stopping distance to maximum effective range for VISION, STEREO, LIDAR, and RADAR sensors (2004 QID and GCE participants).						
Team	**Speed, mph**	**Stopping distance, m**	**Sensor**	**Maximum effective range, m**	**Exceeded**	**Range ratio**
2004-01	45	62.5	Unknown cameras	70.0	N	0.89
			Unknown SICK LIDAR sensors	20.0	Y	3.13
2004-02	50	77.1	SICK LMS 211-30206	20.0	Y	3.86
			Point Grey Bumblebee stereo camera pairs	70.0	Y	1.10
			FLIR A20M camera	70.0	Y	1.10
			Unknown AVT cameras	70.0	Y	1.10
			Epsilon Lambda ELSC71-1A RADAR	50.0	Y	1.54
2004-03	25	19.3	Unknown Cognex cameras	70.0	N	0.28
			Unknown other camera	70.0	N	0.28
			Epsilon Lambda ELSC71-1A RADAR	50.0	N	0.39
2004-04	50	77.1	Unknown Videre Design stereo camera pair	70.0	Y	1.10
			Unknown other cameras	70.0	Y	1.10
			Unknown long-range RADAR	50.0	Y	1.54
			SICK LMS 200-30106	20.0	Y	3.86
2004-05	55	93.3	Unknown SICK LIDAR sensors	20.0	Y	4.67
			Unknown Eaton RADAR	50.0	Y	1.87
			Point Grey Bumblebee stereo camera pair	70.0	Y	1.33
2004-06	60	111.1	Proprietary stereo camera pair	70.0	Y	1.59
2004-07	45	62.5	Unknown SICK LIDAR sensor	20.0	Y	3.13

			Epsilon Lambda ELSC71-1A RADAR	50.0	Y	1.25
			FLIR Omega camera	70.0	N	0.89
			Sony DFW-VL500 cameras	70.0	N	0.89
2004-08	55	93.3	Laseroptronix LDM 800-RS232	20.0	Y	4.67
			Laseroptronix Sea-Lynx	70.0	Y	1.33
			Laseroptronix Sea-Lynx	40.0	Y	2.33
			Cohu 1330 cameras	70.0	Y	1.33
2004-09	60	111.1	Unknown SICK LIDAR sensor	20.0	Y	5.56
			Unknown camera	70.0	Y	1.59
2004-10	36	40.0	Unknown SICK LIDAR sensors	20.0	Y	2.00
			Riegl LMS-Q140i	40.0	N	1.00
2004-11	60	111.1	Unknown long-range laser ranger	40.0	Y	2.78
			Unknown scanning laser range finder	20.0	Y	5.56
			Unknown Omnivision sensor	70.0	Y	1.59
2004-12	40	49.4	SICK LMS 291-S05	20.0	Y	2.47
2004-13	60	111.1	Unknown SICK LIDAR sensors	20.0	Y	5.56
			Unknown camera	70.0	Y	1.59
			Epsilon Lambda ELSC71-1A RADAR	50.0	Y	2.22
2004-14	40	49.4	Unknown cameras	70.0	N	0.71
			Unknown SICK LIDAR sensors	20.0	Y	2.47
			Epsilon Lambda ELSC71-1A RADAR	50.0	N	0.99
2004-15	50	77.1	SICK LMS 211-30206	20.0	Y	3.86
			Eaton EVT-300 RADAR	50.0	Y	1.54

2004-16	30	27.8	Unknown cameras	70.0	N	0.40
			Unknown RADAR	50.0	N	0.56
			Unknown SICK LIDAR sensors	20.0	Y	1.39
2004-17	40	49.4	Point Grey Dragonfly stereo camera pair	70.0	N	0.71
			SICK LMS 221-30206	20.0	Y	2.47
2004-18	60	111.1	Unknown RADAR	50.0	Y	2.22
			SICK LMS 220-30106	20.0	Y	5.56
			Unknown stereo camera pair	70.0	Y	1.59
2004-19	30	27.8	Unknown stereo camera pair	70.0	N	0.40
			SICK DME 2000	20.0	Y	1.39
2004-20	40	49.4	SICK LMS 221-30206	20.0	Y	2.47
			Eaton EVT-300 RADAR	50.0	N	0.99
			Unibrain Fire-i 400 camera	70.0	N	0.71
2004-21	60	111.1	Epsilon Lambda ELSC71-1A RADAR	50.0	Y	2.22
2004-22	60	111.1	Proprietary video system	70.0	Y	1.59
2004-23	50	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
			Unknown Eaton RADAR	50.0	Y	1.54
			Unknown cameras	70.0	Y	1.10
2004-24	25	19.3	Unknown cameras	70.0	N	0.28
			Unknown LIDAR sensor	20.0	N	0.97
			Unknown Eaton RADAR	50.0	N	0.39
2004-25	35	37.8	Unknown camera	70.0	N	0.54
			Unknown SICK LIDAR sensors	20.0	Y	1.89

			Unknown Eaton RADAR	50.0	N	0.76

Table LVII. Field-of-view limitations for VISION, STEREO, LIDAR, and RADAR sensors (2004 QID and GCE participants).							
Team	**Challenge vehicle width, m**	**Sensor**	**Field-of-view, degrees**	**Lane width, m**	**Maximum allowed turn radius, m**	**Number of turns exceeding**	**Lateral obstacle detection distance, m**
2004-01	1.8	Unknown cameras	[a]				
		Unknown SICK LIDAR sensors	[a]				
2004-02	1.8	SICK LMS 211-30206	[a]				
		Point Grey Bumblebee stereo camera pairs	[a]				
		FLIR A20M camera	[a]				
		Unknown AVT cameras	[a]				
		Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	[a]				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	21.7	93.9	41	0.40
2004-03	0.5	Unknown Cognex cameras	[b]				
		Unknown other camera	[b]				
		Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	[a]				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	11.2	23.5	0	[c]
2004-04	1.6	Unknown Videre Design stereo camera pair	[a]				
		Unknown other cameras	[b]				
		Unknown long-range RADAR	[b]				
		SICK LMS 200-30106	[a]				
2004-05	2.2	Unknown SICK LIDAR sensors	[a]				
		Unknown Eaton RADAR	±6	19.2	203.9	182	0.25

		Point Grey Bumblebee stereo camera pair	b				
2004-06	1.9	Proprietary stereo camera pair	b				
2004-07	2.0	Unknown SICK LIDAR sensor	a				
		Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	a				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	17.6	103.0	53	0.40
		FLIR Omega camera	b				
		Sony DFW-VL500 cameras	b				
2004-08	2.2	Laseroptronix LDM 800-RS232	d				
		Laseroptronix Sea-Lynx	±3.75	13.0	508.7	474	0.10
		Cohu 1330 cameras	b				
2004-09	2.0	Unknown SICK LIDAR sensor	a				
		Unknown camera	a				
2004-10	2.1	Unknown SICK LIDAR sensors	a				
		Riegl LMS-Q140i	a				
2004-11	2.4	Unknown long-range laser ranger	d				
		Unknown scanning laser range finder	a				
		Unknown Omnivision sensor	b				
2004-12	1.3	SICK LMS 291-S05	a				
2004-13	1.5	Unknown SICK LIDAR sensors	a				
		Unknown camera	b				
		Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	a				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	30.9	78.3	31	0.40
2004-14	1.8	Unknown cameras	b				

		Unknown SICK LIDAR sensors	a				
		Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	a				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	30.9	91.5	40	0.40
2004-15	1.8	SICK LMS 211-30206	a				
		Eaton EVT-300 RADAR	±6	16.2	163.4	124	0.25
2004-16	1.5	Unknown cameras	b				
		Unknown RADAR	b				
		Unknown SICK LIDAR sensors	a				
2004-17	2.1	Point Grey Dragonfly stereo camera pair	a				
		SICK LMS 221-30206	a				
2004-18	1.4	Unknown RADAR	±6	23.4	125.3	76	0.25
		SICK LMS 220-30106	a				
		Unknown stereo camera pair	b				
2004-19	1.8	Unknown stereo camera pair	a				
		SICK DME 2000	d				
2004-20	2.0	SICK LMS 221-30206	a				
		Eaton EVT-300 RADAR	±6	10.4	182.5	147	0.25
		Unibrain Fire-i 400 camera	b				
2004-21	1.2	Epsilon Lambda ELSC71-1A RADAR (wide-scan mode)	a				
		Epsilon Lambda ELSC71-1A RADAR (narrow-scan mode)	±8	30.9	62.5	19	0.40
2004-22	1.3	Proprietary video system	a				
2004-23	2.5	Unknown SICK LIDAR sensors	a				
		Unknown Eaton RADAR sensors	±6	16.2	227.1	206	0.25

		Unknown cameras	[b]				
2004-24	1.8	Unknown cameras	[b]				
		Unknown LIDAR sensor	[a]				
		Unknown Eaton RADAR	±6	4.1	166.8	128	0.25
2004-25	1.4	Unknown camera	[b]				
		Unknown SICK LIDAR sensors	[a]				
		Unknown Eaton RADAR	±7	9.3	95.3	42	0.34

Notes:

[a] The field-of-view of this sensor equaled or exceeded 40º. As a result, there was no field-of-view limitation. "Lane width", "Maximum allowed turn radius", "Number of turns exceeding", and "Lateral obstacle detection distance" were not calculated.

[b] The field-of-view of this sensor was not reported.

[c] "Lateral obstacle detection distance" exceeded one-half the challenge vehicle width. As a result, there was no field-of-view limitation.

[d] This sensor has no field-of-view.

Table LVIII. Comparison of stopping distance to maximum obstacle detection range for VISION, STEREO, LIDAR, and RADAR sensors (2005 GCE participants).

Team	Speed, mph	Stopping distance, m	Sensor	Maximum obstacle detection range, m	Exceeded	Range ratio
2005-01	50[a]	77.1	Unknown AVT camera	45.7	Y	1.69
			FLIR A20M camera	45.7	Y	1.69
			Point Grey Bumblebee stereo camera pairs	45.7	Y	1.69
			Unknown Eaton RADAR	100.6	N	0.77
			Unknown RADAR	100.6	N	0.77
			Amphitech OASys RADAR	182.9	N	0.42
			SICK LMS 211-30206	82.3	N	0.94
			Unknown SICK LIDAR sensors	82.3	N	0.94
2005-02	50[a]	77.1	SICK LMS 291-S05	[b]		
			Unknown camera	[b]		
2005-03	50[a]	77.1	Proprietary LIDAR sensor	[b]		
2005-04	50[a]	77.1	SICK LMS 221-30206	80.0	N	0.96
			Eaton EVT-300 RADAR	110.0	N	0.70
			Proprietary RADAR	50.0	Y	1.54
			Unknown stereo camera pair	45.0	Y	1.71
2005-05	50[a]	77.1	Unknown SICK LIDAR sensors	80.0	N	0.96
			Mobileye ACP5 camera	[b]		
2005-06	50[a]	77.1	Unknown SICK LIDAR sensors	50.0	Y	1.54
2005-07	50[c]	77.1	Unknown SICK LIDAR sensors	[b]		

			Unknown stereo camera pair	[b]		
2005-08	50[a]	77.1	Riegl LMS-Q120	30.0	Y	2.57
			SICK LMS 291-S14	[b]		
			SICK LMS 211-30106	[b]		
			Delphi Forewarn ACC3 RADAR	152.4	N	0.51
			Sony DFW-VL500 stereo camera pair	[b]		
			Unknown cameras	[b]		
2005-09	50[a]	77.1	Unknown SICK LIDAR sensors	40.0	Y	1.93
2005-10	50	77.1	Unknown SICK LIDAR sensors	30.0	Y	2.57
			Cognex DVT 542C cameras	40.0	Y	1.93
			Unknown stereo camera pair	35.0	Y	2.20
			Optech ILRIS-3D	500.0	N	0.15
2005-11	50[a]	77.1	Unknown SICK LIDAR sensors	[b]		
2005-12	50[a]	77.1	Point Grey Bumblebee stereo camera pair	15.2	Y	5.07
2005-13	35	37.8	Riegl LMS-Q140i	150.0	N	0.25
			Unknown SICK LIDAR sensors	50.0	N	0.76
			Navtech DS2000 RADAR	70.0	N	0.54
2005-14	35	37.8	Riegl LMS-Q140i	150.0	N	0.25
			Unknown SICK LIDAR sensors	50.0	N	0.76
			Navtech DS2000 RADAR	70.0	N	0.54
2005-15	50	77.1	Unknown SICK LIDAR sensors	80.0	N	0.96
			Proprietary stereo camera pair	25.0	Y	3.08
2005-16	35	37.8	Unknown SICK LIDAR sensors	25.0	Y	1.51

			Unknown camera	[b]		
2005-17	25	19.3	Unknown SICK LIDAR sensors	25.0	N	0.77
2005-18	25	19.3	SICK LMS 221-30206	80.0	N	0.24
			SICK LMS 291-S14	80.0	N	0.24
			SICK LMS 291-S05	80.0	N	0.24
			Riegl LMS-Q120i	65.0	N	0.30
			Point Grey Dragonfly cameras	[b]		
2005-19	50[a]	77.1	Unknown SICK LIDAR sensors	80.0	N	0.96
2005-20	50	77.1	Unknown LIDAR sensor(s)	61.0	Y	1.26
			Unknown RADAR	121.9	N	0.63
			Unknown stereo camera pair(s)	61.0	Y	1.26
2005-21	50	77.1	Unknown SICK LIDAR sensors	[b]		
			Unknown Ibeo LIDAR sensor	80.0	N	0.96
			Unknown cameras	[b]		
2005-22	25	19.3	Unknown SICK LIDAR sensor	40.0	N	0.48
			Point Grey Bumblebee stereo camera pair	40.0	N	0.48
2005-23	25	19.3	Unknown SICK LIDAR sensors	[b]		
			Point Grey Bumblebee stereo camera pair	[b]		

Notes:

[a] Challenge vehicle top speed was not reported. The 2005 GCE course-wide speed limit of 50 mph is used herein.

[b] Maximum obstacle detection range for this sensor was not reported.

[c] The Team 2005-07 technical proposal was not available for review. As a result, the 2005 GCE course-wide speed limit of 50 mph is used herein.

Table LIX. Comparison of stopping distance to maximum effective range for VISION, STEREO, LIDAR, and RADAR sensors (2005 GCE participants).						
Team	**Speed, mph**	**Stopping distance, m**	**Sensor**	**Maximum effective range, m**	**Exceeded**	**Range ratio**
2005-01	50[a]	77.1	Unknown AVT camera	70.0	Y	1.10
			FLIR A20M camera	70.0	Y	1.10
			Point Grey Bumblebee stereo camera pairs	70.0	Y	1.10
			Unknown Eaton RADAR	50.0	Y	1.54
			Unknown RADAR	50.0	Y	1.54
			Amphitech OASys RADAR	50.0	Y	1.54
			SICK LMS 211-30206	20.0	Y	3.86
			Unknown SICK LIDAR sensors	20.0	Y	3.86
2005-02	50[a]	77.1	SICK LMS 291-S05	20.0	Y	3.86
			Unknown camera	70.0	Y	1.10
2005-03	50[a]	77.1	Proprietary LIDAR sensor	20.0	Y	3.86
2005-04	50[a]	77.1	SICK LMS 221-30206	20.0	Y	3.86
			Eaton EVT-300 RADAR	50.0	Y	1.54
			Proprietary RADAR	50.0	Y	1.54
			Unknown stereo camera pair	70.0	Y	1.10
2005-05	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
			Mobileye ACP5 camera	70.0	Y	1.10
2005-06	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
2005-07	50[b]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86

			Unknown stereo camera pair	70.0	Y	1.10
2005-08	50[a]	77.1	Riegl LMS-Q120	40.0	Y	1.93
			SICK LMS 291-S14	20.0	Y	3.86
			SICK LMS 211-30106	20.0	Y	3.86
			Delphi Forewarn ACC3 RADAR	50.0	Y	1.54
			Sony DFW-VL500 stereo camera pair	70.0	Y	1.10
			Unknown cameras	70.0	Y	1.10
2005-09	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
2005-10	50	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
			Cognex DVT 542C cameras	70.0	Y	1.10
			Unknown stereo camera pair	70.0	Y	1.10
			Optech ILRIS-3D	40.0	Y	1.93
2005-11	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
2005-12	50[a]	77.1	Point Grey Bumblebee stereo camera pair	70.0	Y	1.10
2005-13	35	37.8	Riegl LMS-Q140i	40.0	N	0.95
			Unknown SICK LIDAR sensors	20.0	Y	1.89
			Navtech DS2000 RADAR	50.0	N	0.76
2005-14	35	37.8	Riegl LMS-Q140i	40.0	N	0.95
			Unknown SICK LIDAR sensors	20.0	Y	1.89
			Navtech DS2000 RADAR	50.0	N	0.76
2005-15	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
			Proprietary stereo camera pair	70.0	Y	1.10
2005-16	35	37.8	Unknown SICK LIDAR sensors	20.0	Y	1.89

			Unknown camera	70.0	N	0.54
2005-17	25	19.3	Unknown SICK LIDAR sensors	20.0	N	0.97
2005-18	25	19.3	SICK LMS 221-30206	20.0	Y	2.47
			SICK LMS 291-S14	20.0	Y	2.47
			SICK LMS 291-S05	20.0	Y	2.47
			Riegl LMS-Q120i	40.0	Y	1.24
			Point Grey Dragonfly cameras	70.0	N	0.71
2005-19	50[a]	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
2005-20	50	77.1	Unknown LIDAR sensor(s)	20.0	Y	3.86
			Unknown RADAR	50.0	Y	1.54
			Unknown stereo camera pair(s)	70.0	Y	1.10
2005-21	50	77.1	Unknown SICK LIDAR sensors	20.0	Y	3.86
			Unknown Ibeo LIDAR sensor	40.0	Y	1.93
			Unknown cameras	70.0	Y	1.10
2005-22	25	19.3	Unknown SICK LIDAR sensor	20.0	N	0.97
			Point Grey Bumblebee stereo camera pair	70.0	N	0.28
2005-23	25	19.3	Unknown SICK LIDAR sensors	20.0	N	0.97
			Point Grey Bumblebee stereo camera pair	70.0	N	0.28

Notes:

[a] Challenge vehicle top speed was not reported. The 2005 GCE course-wide speed limit of 50 mph is used herein.

[b] The Team 2005-07 technical proposal was not available for review. As a result, the 2005 GCE course-wide speed limit of 50 mph is used herein.

Table LX. Field-of-view limitations for VISION, STEREO, LIDAR, and RADAR sensors (2005 GCE participants).						
Team	**Challenge vehicle width, m**	**Sensor**	**Field-of-view, degrees**	**Lane width, m**	**Maximum allowed turn radius, m**	**Number of turns exceeding**
2005-01	1.8	Unknown AVT camera	[a]			
		FLIR A20M camera	[a]			
		Point Grey Bumblebee stereo camera pairs	[a]			
		Unknown Eaton RADAR	[a]			
		Unknown RADAR	[a]			
		Amphitech OASys RADAR	[a]			
		SICK LMS 211-30206	[a]			
		Unknown SICK LIDAR sensors	[a]			
2005-02	[c]	SICK LMS 291-S05	[a]			
		Unknown camera	[b]			
2005-03	1.9	Proprietary LIDAR sensor	[a]			
2005-04	1.5	SICK LMS 221-30206	[a]			
		Eaton EVT-300 RADAR	±6	16.2	139.1	142
		Proprietary RADAR	[a]			
		Unknown stereo camera pair	[a]			
2005-05	2.0	Unknown SICK LIDAR sensors	[a]			
		Mobileye ACP5 camera	[a]			
2005-06	1.8	Unknown SICK LIDAR sensors	±15	21.4	26.4	7
2005-07	[d]	Unknown SICK LIDAR sensors	[a]			

		Unknown stereo camera pair	d			
2005-08	2.0	Riegl LMS-Q120	a			
		SICK LMS 291-S14	a			
		SICK LMS 211-30106	a			
		Delphi Forewarn ACC3 RADAR	a			
		Sony DFW-VL500 stereo camera pair	a			
		Unknown cameras	a			
2005-09	1.8	Unknown SICK LIDAR sensors	a			
2005-10	1.8	Unknown SICK LIDAR sensors	a			
		Cognex DVT 542C cameras	±15	21.4	26.4	7
		Unknown stereo camera pair	a			
		Optech ILRIS-3D	a			
2005-11	1.2	Unknown SICK LIDAR sensors	a			
2005-12	1.7	Point Grey Bumblebee stereo camera pair	a			
2005-13	2.1	Riegl LMS-Q140i	a			
		Unknown SICK LIDAR sensors	a			
		Navtech DS2000 RADAR	a			
2005-14	2.1	Riegl LMS-Q140i	a			
		Unknown SICK LIDAR sensors	a			
		Navtech DS2000 RADAR	a			
2005-15	1.5	Unknown SICK LIDAR sensors	a			
		Proprietary stereo camera pair	b			
2005-16	1.9	Unknown SICK LIDAR sensors	a			

		Unknown camera	[b]			
2005-17	2.1	Unknown SICK LIDAR sensors	[a]			
2005-18	2.0	SICK LMS 221-30206	[a]			
		SICK LMS 291-S14	[a]			
		SICK LMS 291-S05	[a]			
		Riegl LMS-Q120i	[b]			
		Point Grey Dragonfly cameras	[b]			
2005-19	[c]	Unknown SICK LIDAR sensors	[a]			
2005-20	1.0[e]	Unknown LIDAR sensor(s)	[a]			
		Unknown RADAR	±6	16.2	182.5	193
		Unknown stereo camera pair(s)	[a]			
2005-21	2.5	Unknown SICK LIDAR sensors	[a]			
		Unknown Ibeo LIDAR sensor	[a]			
		Unknown cameras	[b]			
2005-22	1.5	Unknown SICK LIDAR sensor	[a]			
		Point Grey Bumblebee stereo camera pair	[b]			
2005-23	1.5	Unknown SICK LIDAR sensors	[a]			
		Point Grey Bumblebee stereo camera pair	[b]			

Notes:

[a] The field-of-view of this sensor equaled or exceeded 40°. As a result, there was no field-of-view limitation. "Lane width", "Maximum allowed turn radius", "Number of turns exceeding", and "Lateral obstacle detection distance" were not calculated.

[b] The field-of-view of this sensor was not reported. As a result, "Lane width", "Maximum allowed turn radius", "Number of turns exceeding", and "Lateral

obstacle detection distance" were not calculated.

[c] Challenge vehicle width was not reported.

[d] The Team 2005-07 technical proposal was not available for review. As a result, "Lane width", "Maximum allowed turn radius", "Number of turns exceeding", and "Lateral obstacle detection distance" were not calculated.

[e] Challenge vehicle width was not reported. The author estimated the width of the Team 2005-20 challenge vehicle as 2.0 m.

Table LXI. Number of sensors for which stopping distance exceeded maximum obstacle detection range.		
	2004 (71 sensors)	**2005 (60 sensors)**
Number of sensors	34 (48 percent)	16 (27 percent)
Average safety factor	1.61[a]	1.16[b]

Notes:

[a] Maximum obstacle detection ranges for 14 sensors were not reported. Average safety factor was calculated for 57 sensors for which the maximum obstacle detection range was reported.

[b] Maximum obstacle detection ranges for 17 sensors were not reported. Average safety factor was calculated for 43 sensors for which the maximum obstacle detection range was reported.

Table LXII. Number of sensors for which stopping distance exceeded maximum effective range.		
	2004 (66 sensors)	**2005 (60 sensors)**
Number of sensors	46 (70 percent)	49 (82 percent)
Average safety factor	1.88	2.31

Table LXIII. Number of teams for which stopping distance exceeded the maximum obstacle detection range of sensors in use.		
Number of teams	**2004**[a]	**2005**[b]
All sensors	10 (43 percent)	4 (22 percent)
One or more sensors	7 (30 percent)	6 (33 percent)
No sensors	6 (26 percent)	8 (44 percent)

Notes:

[a] Teams 2004-24 and 2004-25 did not report maximum obstacle detection range for any sensors in use by the team.

[b] Teams 2005-02, 2005-03, 2005-07, 2005-11, and 2005-23 did not report maximum obstacle detection range for any sensors in use by the team.

Table LXIV. Number of teams for which stopping distance exceeded the maximum effective range of sensors in use.		
Number of teams	**2004**	**2005**
All sensors	14 (56 percent)	16 (70 percent)
One or more sensors	9 (36 percent)	4 (17 percent)
No sensors	2 (8 percent)	3 (13 percent)

Table LXV. Average ratio of stopping distance to range for sensors in use by teams which participated in both the 2004 and 2005 GCE.					
Team	**Average ratio**		**Team**	**Average ratio**	
	Maximum obstacle detection range	**Maximum effective range**		**Maximum obstacle detection range**	**Maximum effective range**
2004-10	1.07	1.50	2005-13	0.52	1.20
2004-23	1.16	2.17	2005-21	0.96[a]	2.30
2004-18	1.74	3.12	2005-20	1.05	2.17
2004-02	1.74	1.74	2005-01	1.11	1.96
2004-25	[b]	1.06	2005-22	0.48	0.63
2004-06	1.22	1.59	2005-03	[b]	3.86
2004-08	0.48	2.42	2005-07	[b]	2.48
2004-07	3.30	1.54	2005-05	0.96[a]	2.48
2004-16	0.29	0.78	2005-17	0.77	0.97
2004-13	1.80	3.12	2005-15	2.02	2.48
2004-04	2.55	1.90	2005-02	[b]	2.48
2004-17	1.65	1.59	2005-18	0.26[a]	1.87
AVERAGE	1.55	1.88	AVERAGE	0.90	2.07

Notes:

[a] The team did not report the maximum obstacle detection range for one or more sensors in use by the team.

[b] The team did not report the maximum obstacle detection range for all sensors in use by the team.

Table LXVI. Primary group identity and sponsorship of teams participating in the 2004 QID and GCE.								
Team	Primary group identity	Sponsorship						GCE
		Corporate			Academic			
		L	M	E	L	M	E	
2004-10	Academic			X			X	7.4
2004-14	Corporate		X					6.7
2004-06	Individual	X						6.0
2004-07	Individual	X						5.2
2004-17	Academic		X			X		1.3
2004-23	Corporate			X	X			1.2
2004-13	Corporate		X					0.75
2004-04	Academic		X				X	0.45
2004-18	Corporate		X					0.20
2004-02	Individual	X						0.0
2004-09	Academic		X		X			0.0
2004-16	Academic		X			X		0.0
2004-25	Academic		X			X		0.0
2004-03	Academic	X			X			WD
2004-24	Individual							WD
2004-01	Individual	X						–
2004-05	Individual	X						–
2004-08	Individual	X						–
2004-11	Individual	X						–
2004-12	Individual							–
2004-15	Academic	X			X			–
2004-19	Individual	X						–
2004-20	Individual		X					–
2004-21	Individual	X						–
2004-22	Individual							–

Table LXVII. Primary group identity and sponsorship of teams participating in the 2005 GCE.

Team	Primary group identity	Sponsorship						GCE
		Corporate			Academic			
		L	M	E	L	M	E	
2005-16	Academic		X				X	131.7
2005-13	Academic			X			X	131.7
2005-14	Academic			X			X	131.7
2005-06	Individual		X					131.7
2005-21	Corporate			X	X			131.7
2005-20	Corporate		X					81.2
2005-01	Individual	X						66.2
2005-22	Academic		X			X		43.5
2005-23	Academic		X			X		39.4
2005-04	Academic	X					X	29.0
2005-03	Individual	X						26.2
2005-07	Individual	X						25.6
2005-10	Individual	X						23.0
2005-05	Individual	X			X			22.4
2005-17	Academic		X			X		17.2
2005-15	Corporate		X			X		15.9
2005-08	Individual		X					14.0
2005-02	Academic		X				X	13.6
2005-12	Academic	X				X		9.5
2005-19	Academic		X			X		8.9
2005-18	Academic		X			X		8.0
2005-11	Individual	X						7.2
2005-09	Corporate		X					0.7

Table LXVIII. Sponsorship of teams which participated in both the 2004 and 2005 GCE.

Team	Sponsorship						Team	Sponsorship					
	Corporate			Academic				Corporate			Academic		
	L	M	E	L	M	E		L	M	E	L	M	E
2004-10			X			X	2005-13			X			X
2004-23			X	X			2005-21			X	X		
2004-18		X					2005-20		X				
2004-02	X						2005-01	X					
2004-25		X			X		2005-22		X			X	
2004-06	X						2005-03	X					
2004-08	X						2005-07	X					
2004-07	X						2005-05	X			X		
2004-16		X			X		2005-17		X			X	
2004-13		X					2005-15		X			X	
2004-04		X				X	2005-02		X				X
2004-17		X			X		2005-18		X			X	

Table LXIX. Number of preventable failures reported by teams participating in the 2005 GCE.				
Team	**Number of failures reported**			**Preventable failures**
	Controlling intelligence	**System integration**	**Other**	
2005-02		1	1	1
2005-05	1	2		3
2005-06		2	2	2
2005-09		2		2
2005-12		4	1	4
2005-13/14		1	1	1
2005-15		2		1
2005-17		4	1	4
2005-18	2	2		2
2005-19		2		2
2005-22/23		1		1
TOTAL	3	23	6	23

Table LXX. Reported ranges of 2004 challenge vehicles.	
Team	**Range (miles)**
2004-01	350
2004-02	400
2004-03	230
2004-04	300
2004-05	320
2004-06	700[a]
2004-07	500
2004-08	460
2004-09	300
2004-10	"... in excess of 300km..." ([77], p. 4)[b]
2004-11	350
2004-12	250
2004-13	300
2004-14	400
2004-15	300 – 350
2004-16	200
2004-17	250
2004-18	256[c]
2004-19	250
2004-20	250 – 350
2004-21	300
2004-22	350
2004-23	600
2004-24	400
2004-25	300

Notes:

[a] Team 2004-06 did not report the range of the Team 2004-06 challenge vehicle. Team 2004-06 stated: "The vehicle will be retrofitted with an extra fuel cell to provide an additional 50-gallon capacity." ([114], p. 3). Team 2004-06 selected a 2003 Toyota

Tundra (SR5 V8 Access Cab) as challenge vehicle platform. See Table XV. The manufacturer minimum "mileage estimate" for this vehicle is 14 miles per gallon ([258]). The author estimated the range of the Team 2004-06 challenge vehicle was 700 miles.

[b] 300 km is approximately 186.4 miles. Team 2004-10 reported the range of the Team 2004-10 challenge vehicle was "...in excess of [the] prescribed course..." ([77], p. 7). However, the proposed 2004 GCE course length was "approximately 250 miles" ([261]) on October 14, 2003, the date technical proposals were required to be submitted to DARPA, and DARPA did not report the proposed 2004 GCE course length via revision "5 January 2004" of the 2004 GCE rules. See Appendix C. Team 2004-10 submitted several revisions of their technical proposal. The revision published by DARPA was dated April 8, 2004, approximately six months after technical proposals were required to be submitted to DARPA on October 14, 2003.

[c] Team 2004-18 stated: "The vehicle is estimated to get an average of 16 mpg and the 16 gallons of fuel will provide approximately 2560 miles of total range." ([48], p. 10). However, this is in error.

Table LXXI. Electrical power generation strategies for teams which participated in the 2004 GCE.						
Team	**Alternator**	**Alternator and batteries**	**Generator**	**Generator and batteries**	**Platform type[a]**	**GCE**
2004-10				X	4	7.4
2004-14		X			3	6.7
2004-06	X				2	6.0
2004-07				X	2	5.2
2004-17				X	1	1.3
2004-23[b]	X				4	1.2
2004-13			X		3	0.75
2004-04			X		1	0.45
2004-18[c]	X				3	0.20
2004-02		X			1	0.0
2004-09	X				1	0.0
2004-16[d]				X	3	0.0
2004-25				X	3	0.0
2004-03		X			[e]	WD
2004-24				X	5	WD

Notes:

[a] See Table XIV for a description of challenge vehicle platform type.

[b] Team 2004-23 stated: "The diesel engine will supply both driveline power and electrical power for instrumentation and drive-by-wire components." ([159], p. 3). Team 2004-23 did not report a generator or batteries were in use by the team. The author concluded an alternator was in use by Team 2004-23 to generate electrical power.

[c] Team 2004-18 did not report the electrical power generation strategy in use by the team. Team 2004-18 stated: "The stock 649cc single cylinder four-stroke engine running with high-octane pump fuel will supply the power." and "The engine will supply all the power." ([48], p. 2). Team 2004-18 did not report a generator was in use by the team. Team 2004-18 also stated: "Seven sealed lead acid batteries (20 amp-hr) or equivalent are used to operate the engine starter motor and lights when the engine is not running, and the steering, throttle and the choke when the engine is running." ([48],

p. 2). The author concluded an alternator was in use by Team 2004-18 to generate electrical power.

[d] Via Figure 6 ("E-Power Subsystem") of the team technical proposal ([138], p. 9), Team 2004-16 reported one "2300W Generator" was in use by the team to generate electrical power through an UPS separate from the challenge vehicle battery.

[e] Team 2004-03 selected a motorcycle as challenge vehicle platform. See Table XV.

Table LXXII. Electrical power generation strategies for teams which participated in the 2005 GCE.

Team	Alternator	Alternator and batteries	Generator	Generator and batteries	Platform type[a]	GCE[43]
2005-16	X				1	131.7
2005-13			X		4	131.7
2005-14			X		1	131.7
2005-06[b]					1	131.7
2005-21[c]	X				4	131.7
2005-20[d]	X				5	81.2
2005-01		X			1	66.2
2005-22[e]				X	3	43.5
2005-23[e]				X	3	39.4
2005-04			X		3	29.0
2005-03[f]	X				2	26.2
2005-07[g]					1	25.6
2005-10[h]	X				1	23.0
2005-05[i]	X				2	22.4
2005-17			X		3	17.2
2005-15			X		3	15.9
2005-08		X			2	14.0
2005-02[j]		X			5	13.6
2005-12		X			2	9.5
2005-19			X		4	8.9
2005-18				X	[k]	8.0
2005-11		X			3	7.2
2005-09	X				1	0.7

Notes:

[a] See Table XIV for a description of challenge vehicle platform type.

[b] Team 2005-06 was the only team which participated in either the 2004 or 2005 GCE to

select a commercially-available hybrid vehicle as challenge vehicle platform. See Table XVI. This vehicle is therefore unique. See paragraph XIV.B.1.b.i.

[c] Team 2005-21 did not report the electrical power generation strategy in use by the team ([160]). Team 2005-21 participated in the 2005 GCE as Team 2004-23. Team 2004-23 stated: "The diesel engine will supply both driveline power and electrical power for instrumentation and drive-by-wire components." ([159], p. 3). The author considers it likely a similar strategy was in use by Team 2005-21 to generate electrical power and concluded an alternator was in use by the team.

[d] Team 2005-20 did not report the electrical power generation strategy in use by the team ([56]). The author considers it likely an alternator was in use by Team 2005-20 to generate electrical power.

[e] Teams 2005-22 and Team 2005-23 did not report the electrical power generation strategy in use by the teams ([58] and [164]). Although Teams 2005-22 and 2005-23 later stated: "This section includes the details of the base vehicles, power system, drive-by-wire conversion, and network architecture..." ([59], p. 710), the teams did not report the electrical power generation strategy in use by the teams. However, Team 2005-23 failed to complete the 2005 GCE because the challenge vehicle's "on-board generator shut down due to a suspected false low-oil reading.". See paragraph XIII.B.14. In addition, Team 2004-25 reported a generator and batteries were in use by the team. As a result, the author considers it likely a similar strategy was in use by Teams 2005-22 and 2005-23 to generate electrical power, and concluded a generator and batteries were in use by the teams.

[f] Team 2005-03 stated: "The vehicle will be stock except for desert racing tires and a retrofitted extra fuel cell to provide a total fuel capacity of approximately 40 gallons." ([33], p. 4). Throughout their technical proposal, Team 2005-03 reported selecting low-power components. The author concluded an alternator was in use by Team 2005-03 to generate electrical power.

[g] The hyperlink to the Team 2005-07 technical paper hosted by the Archived Grand Challenge 2005 website ([19]) is a hyperlink to the team website, and the author was unable to locate a copy of the Team 2005-07 technical paper on the team website. As a result, the author concluded the technical paper was unavailable for review. See paragraph V.C.32.

[h] Team 2005-10 did not report the electrical power generation strategy in use by the team ([176]). Team 2005-10 stated: "Our vehicle is a commercially available 2001 Nissan Xterra SUV... The rational for this choice was that we didn't want to spend time designing and building a vehicle. We wanted to spend time on the sensory and navigation systems, so we bought a commercial vehicle that was as close as possible to what was needed and modified it in the ways described above." ([176], p. 2). The

author concluded an alternator was in use by Team 2005-10 to generate electrical power.

[i] Team 2005-05 did not report the electrical power generation strategy in use by the team ([34]). Team 2005-05 later stated: "Each of our vehicles was a commercially available pickup truck, fitted with electrically actuated steering and throttle, and pneumatically actuated brakes." ([170], p. 529). Team 2005-05 did not report a generator or batteries were in use by the team. The author concluded an alternator was in use by Team 2005-05 to generate electrical power.

[j] Team 2005-02 did not report the electrical power generation strategy in use by the team ([167]). Team 2005-02 later stated: "The power system consists of two independent 140 A 28 V alternator systems... Each alternator drives a 2400 W continuous, 4800 W peak inverter and is backed up by four deep-cell batteries." ([50], p. 604).

[k] Team 2005-18 selected a 2005 Ford E-350 Van as challenge vehicle platform. See Table XVI.

Table LXXIII. Manufacturer index[a].	
Manufacturer name	**Short name**
Advanced Micro Devices, Inc.	AMD
ALK Technologies, Inc.	ALK
Allied Vision Technologies GmbH	AVT
AM General, LLC	AM General
American GNC Corp.	AGNC
Amphitech Systems, Inc.	Amphitech
Analog Devices, Inc.	Analog Devices
Applanix Corp.	Applanix
Basler AG	Basler
BEI Technologies, Inc.	BEI
Bendix Commercial Vehicle Systems, LLC	Bendix
Bodine Electric Co.	Bodine Electric
Boeing Co.	Boeing
C&C Technologies, Inc.	C&C Technologies
Caterpillar, Inc.	Caterpillar
Cognex Corp.	Cognex
Cohu, Inc.	Cohu
Crossbow Technology, Inc.	Crossbow
CSI Wireless, Inc.	CSI Wireless
Delphi Corp.	Delphi
DICKEY-john Corp.	DICKEY-john
DVT Corp.	DVT
Eaton Corp.	Eaton
Edmunds, Inc.	Edmunds
The Eigenpoint Co.	Eigenpoint
Electro Switch Corp.	Electro Switch
Epsilon Lambda Electronics Corp.	Epsilon Lambda
FLIR Systems, Inc.	FLIR
Ford Motor Co.	Ford

Garmin, Ltd.	Garmin
General Electric Co.	GE
General Motors Co.	GM
American Honda Motor Co.	Honda
Honeywell International, Inc.	Honeywell
Ibeo Automotive Sensor GmbH	Ibeo
Indigo Systems Corp.	Indigo
Inertial Science, Inc.	ISI
Intel Corp.	Intel
Japan Servo Co.	Japan Servo
Kearfott Corp.	Kearfott
KVH Industries, Inc.	KVH
Laseroptronix AB	Laseroptronix
Litton Industries, Inc.	Litton
Microbotics, Inc.	Microbotics
MiTAC International Corp.	MiTAC
Mobileye, Ltd.	Mobileye
Motion Systems Corp.	Motion Systems
MotorTrend Magazine	MotorTrend
NavCom Technology, Inc.	NavCom
Navtech RADAR, Ltd.	Navtech
Northrop Grumman Corp.	Northrop Grumman
NovAtel, Inc.	NovAtel
OmniSTAR, Inc.	OmniSTAR
Omnivision Technologies, Inc.	Omnivision
Omron Corp.	Omron
Optech, Inc.	Optech
Oshkosh Corp.	Oshkosh
Oxford Technical Solutions, Ltd.	Oxford
PNI Sensor Corp.	PNI
Point Grey Research, Inc.	Point Grey
Preco Electronics	Preco

Recreative Industries, Inc.	Recreative Industries
RIEGL Laser Measurement Systems GmbH	Riegl
Rockwell Automation, Inc.	Rockwell Automation
Rotomotion, LLC	Rotomotion
Science Applications International Corp.	SAIC
SensComp, Inc.	SensComp
SICK AG	SICK
Smart Microwave Sensors GmbH	Smart Microwave
SpaceAge Control, Inc.	SpaceAge
SRI International	SRI
Systron Donner Inertial	Systron Donner
Thales Navigation	Thales Navigation
TOMCAR USA, Inc.	Tomcar
Toyota Motor Corp.	Toyota
Trimble Navigation, Ltd.	Trimble
u-blox AG	u-blox
Ultra Motion	Ultra Motion
Unibrain, Inc.	Unibrain
Vansco Electronics, Inc.	Vansco
Videre Design, LLC	Videre Design

Notes:

[a] Manufacturers are referred to herein by short name. For example, Inertial Sciences, Inc. is referred to as "ISI". In general, the author selected the short name based on manufacturer custom, i.e., the short name by which the manufacturer refers to itself, and not the short names selected by the teams, which were frequently in error.