



NTNU

Innovation and Creativity

Systems engineering saves the day! (0 / 1 / 2)

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IS2012

9 July 2012



Shell Eco-marathon Europe

The Shell Eco-marathon challenges high school and college student teams from around the world to design, build and test energy efficient vehicles.

With annual events in the Americas, Europe and Asia, the winners are the teams that go the farthest distance using the least amount of energy.



Background

- NTNU has participated since 2008
- Team made up of Masters level students from multiple disciplines
- Holds the world record for the Urban Concept Fuel Cell class (2009)
- 2010 ... failed to pass preliminary inspection
- 2011 ... determined to be in the winner's circle again



Sponsorship

- Students rely on sponsorship to fund the work and travel expenses for competition
- 2009 – 2010 sponsor reluctant to back the team again
- Eventually Den norske Veritas (DNV) agreed, but not until late in December

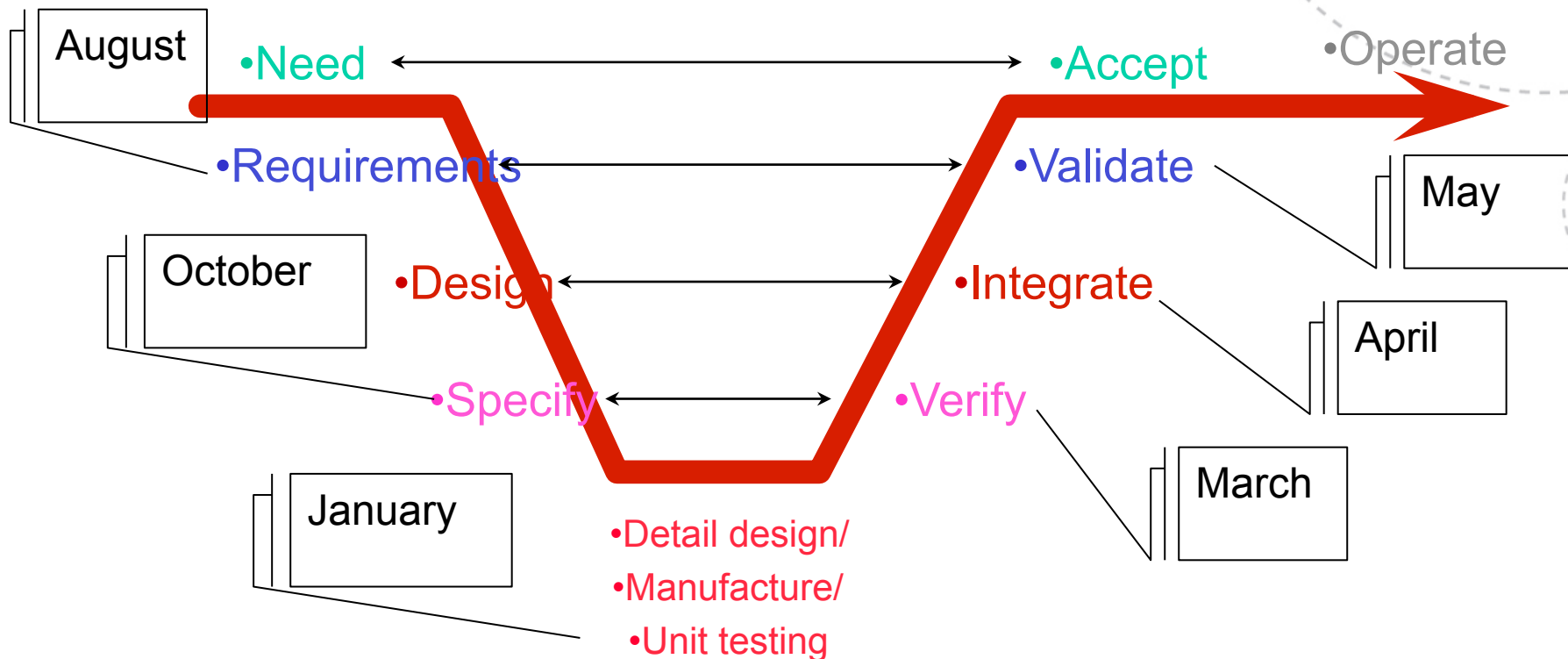


Project stakeholders

- NTNU faculty
- Students from mechanical and electrical engineering, control systems, and project management studies
- Sponsors
- External entities
- Shell (customer)



Project timeline





Missing: the Systems Engineer

From 0 to 1 SE overnight

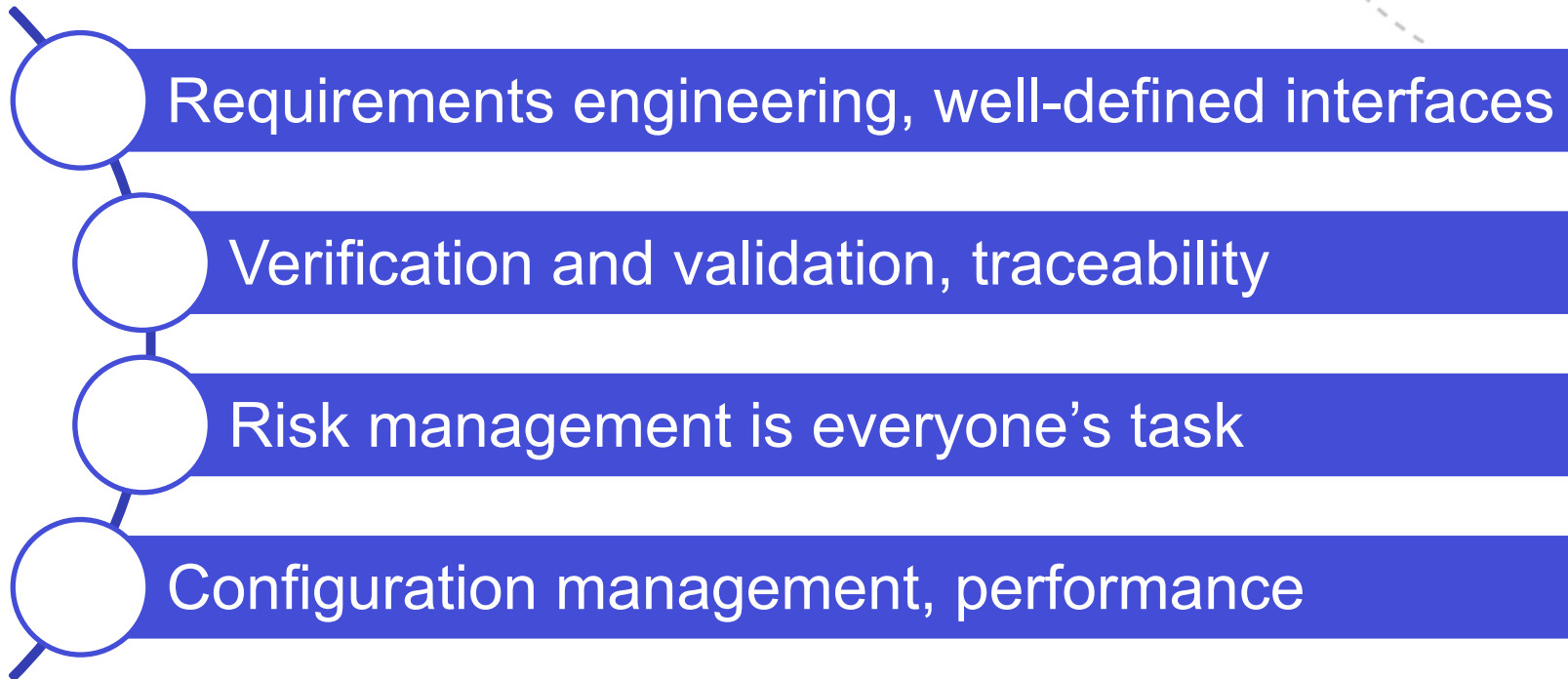


6Cs contributions of the systems engineer

- Comprehension - understanding
- Communication – translator services
- Coordination – harmonious functioning
- Cooperation – work toward a goal
- Collaboration – stakeholders, partners
- Continuity – over the life cycle



Pillars of systems engineering





Team Photo / Before

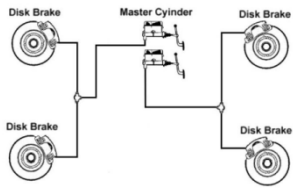


Systems Engineering within development and construction of the Eco-marathon car:

- Continuous improvement for next year's team
- The car was viewed as a system with individual sub-systems and identified interfaces
- Necessary external technical and organisational support system connecting to building, testing transportation and the race



•Brake System



Complex system of different Components

•Body



Figure 23: Near- and far front lights working correctly.

•Rims



•Dashboard



Figure 26: Inside the cockpit, accelerator encoder lying below the steering wheel, LCD panel active.



Figure 25: LCD panel showing the main menu.

•Suspension



Figure 16: Front suspension

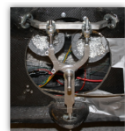


Figure 19: Rear suspension, engine side



Figure 19: Rear suspension, steering side

•Engine

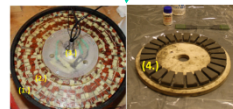


Figure 17: Engine, engine side

•Fuel Cell

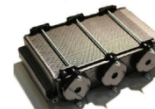


Figure 18: Mark 1020 ACS



•Control System

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•The race track in Germany 2011



Know your track

Impact on braking functions, suspension, turning radius, etc.



What did we do?

ID:	Supporting documents:	Description:
D.1	Total requirements document:	Describes all the modules and their requirement according to the Shell Eco-marathon rules
D.2	Architecture design: -Complete system	Describes the complete system
D.3	Architecture design: -Mechanical	Describes the mechanical modules related to the car
D.4	Architecture design: -Electronic	Describes the mechanical modules related to the car
D.5	Architecture design: -Component dependencies	Describes the mechanical modules related to the car
D.X.	Module documents:	Describes a document with the, system architecture, requirements, function, interfaces, interface testing and risk.



Article	Requirements	System	Responsible	Status
47	Vehicle Design			
47.1	UrbanConcept vehicles must have exactly four wheels , which under normal running conditions must be all in continuous contact with the road. A fifth wheel for any purpose is forbidden.	S.7 Wheels	SB/TMS	ok
47.2	Aerodynamic appendages, which adjust or are prone to changing shape due to wind whilst the vehicle is in motion, are forbidden (e.g. no shrink wrap allowed).	S.1 Body	TMS	ok
47.3	Vehicle bodies must not include any external appendages that might be dangerous to other Team members; e.g. sharp points must have a radius of 5cm or greater, alternatively they should be made of foam or similar deformable material. <i>This means for example exposed corners of solar panels, pointed parts of the vehicle body, etc.</i>	S.1 Body	TMS	Ok
47.4	The vehicle interior must not contain any objects that might injure the Driver during a collision.	S.1 Body	TMS/SB	ok
47.5	Windows must not be made of any material which may shatter into sharp shards. Recommended material: Polycarbonate (e.g. Lexan)	S.1 Body	TMS	ok
48	Dimensions			
48.1	The total vehicle height must be between 100cm and 130cm.	S.1 Body	TMS	99 cm. Does not comply at the moment. Could be adjusted by tire pressure

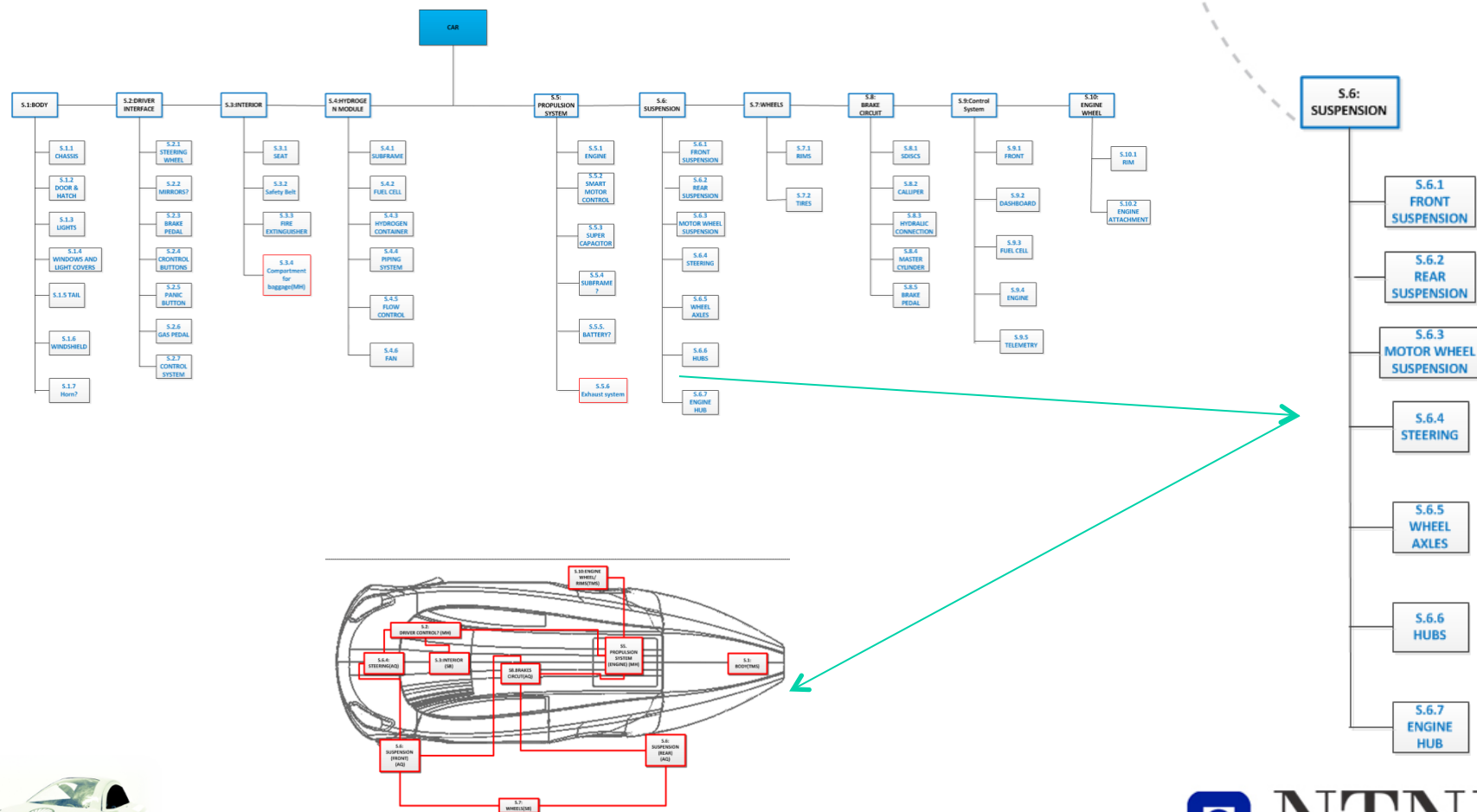
D.1 Total Requirements checklist

Requirements traceability

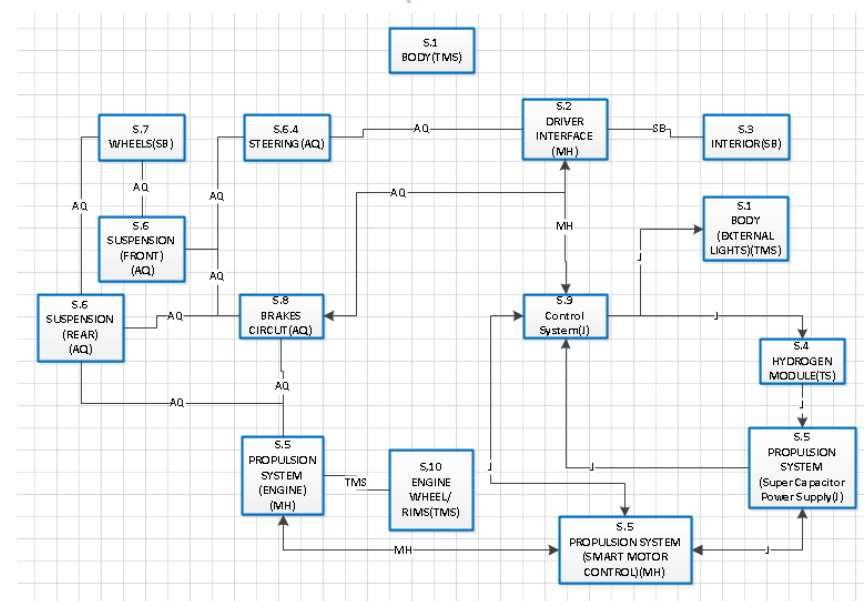
All requirements from Shell



D.2 Defining the physical Architecture



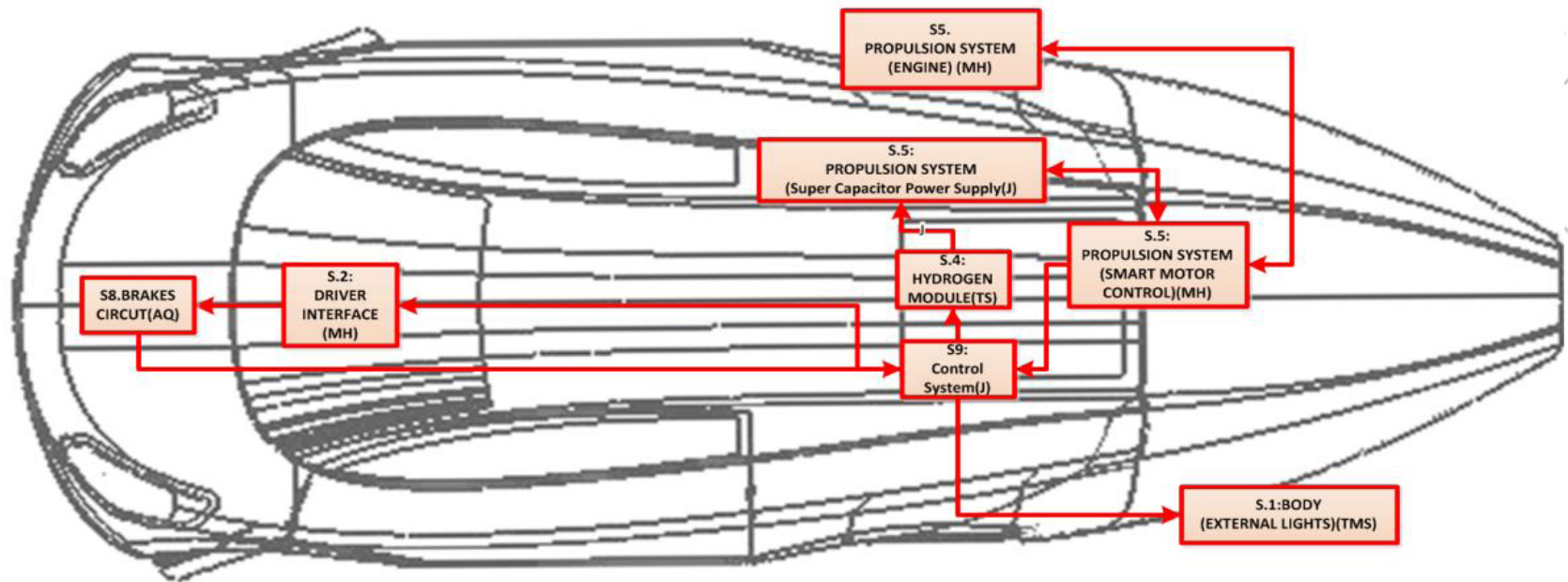
Interfaces



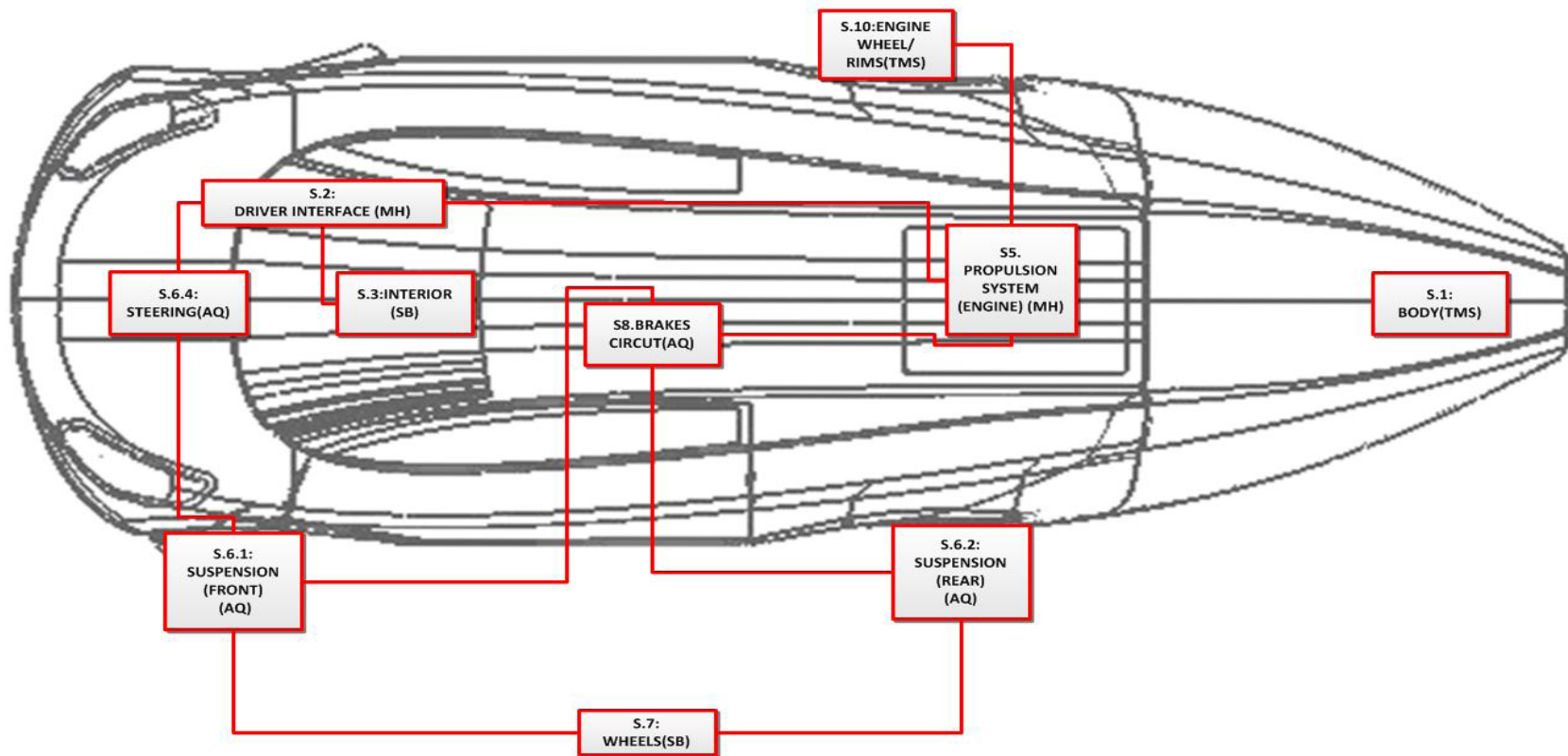
- Each interface had an **owner**



Electronic interfaces



Mechanical interfaces



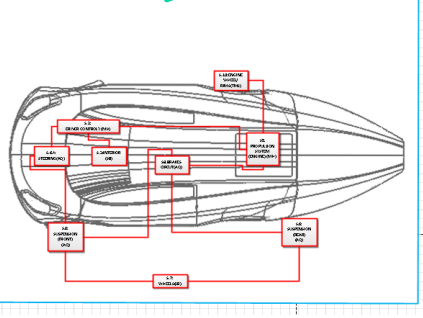
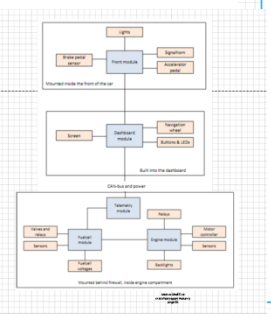
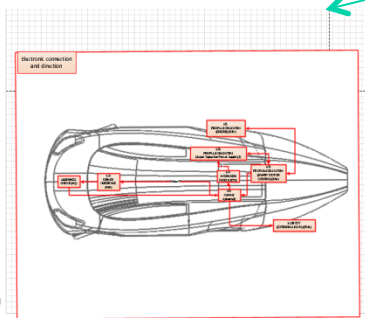
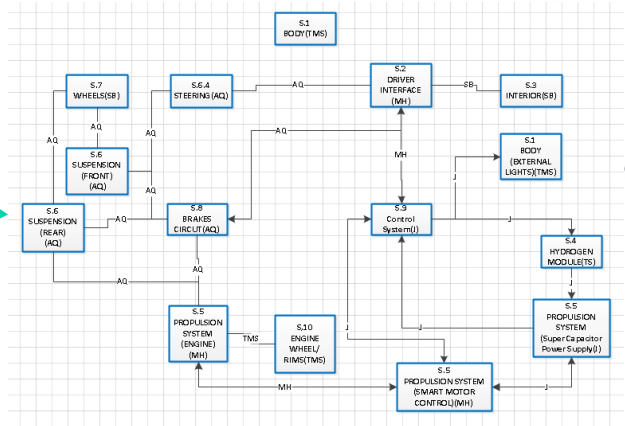
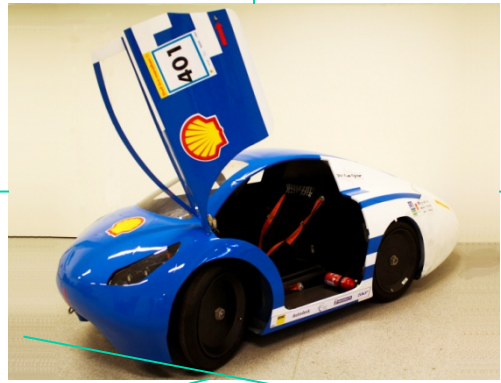
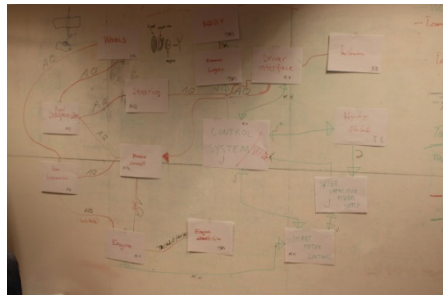
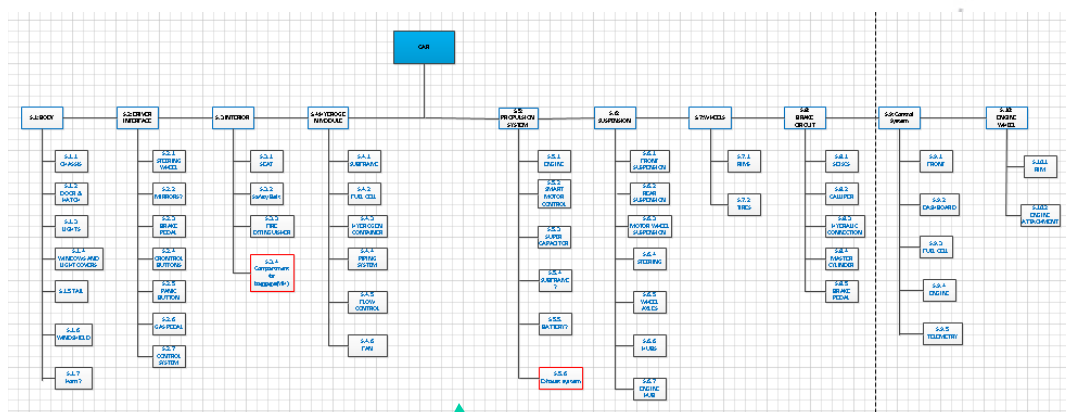
D.X Sub System Documents

- D.6 Suspension Concept and final design

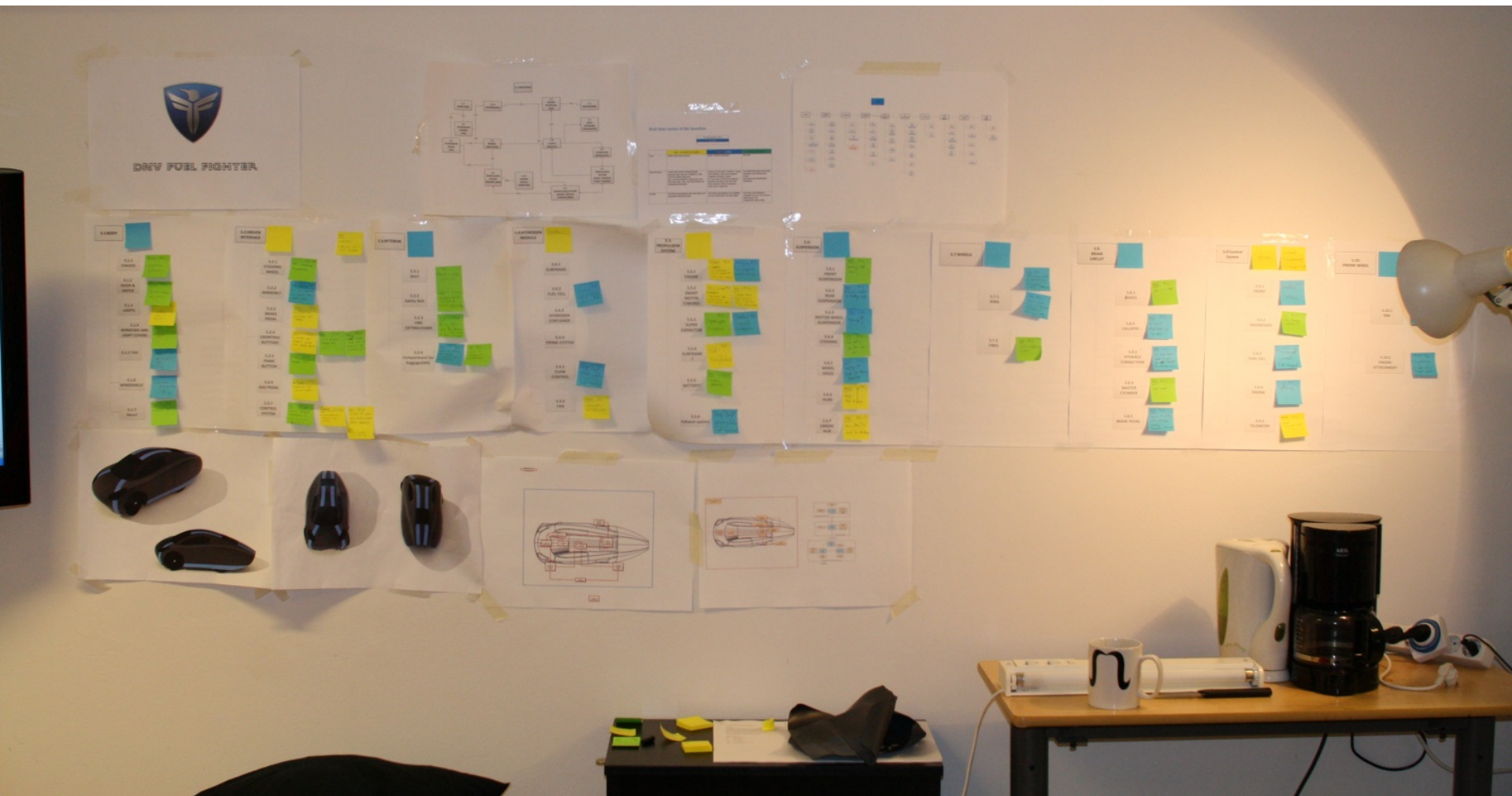
4.2 Requirement document

ID	Requirement	Interface requirement	Function (The System Shall)	Value/Comments	Should	Must
S.6	Article 48.4 Article 48.5 Article 56.1 Article 56.2 Article 56.3 Article 56.4 Article 56.5	S.2 Driver interface S.5 Propulsion System S.7 Wheels S.8 Brake Circuit	Support the wheels and give stable control of the car	Official Shell rules		X
S.6.4	Easily tightened wire		Shall steer the car	We need a new tightening device	X	
S.6.1	Support curve of 6m radius in 30 km/t without fractures		Shall support the wheels and steering			X
S.6.1-2	Adjustable in 3 axes		Shall support the wheels and steering			X
S.6.1-2	Toe-in 0 degrees on front and rear wheels		Shall support the wheels and steering			X
S.6.1-3	0 degrees camber when loaded					X
S.6.1	6 degrees caster on front wheels					X
S.6.1	0 mm scrub radius			Impossible without making an entirely new suspension, anchor points and new rim design.	X	
S.6.1	No bump steer			Body and suspension consider stiff enough to minimize bump steer.	X	
S.6.1	6 degrees king-pin angle			Impossible. Previous calculations based on wrong geometry	X	
S.6.1-2 S.6.7	Lowest possible friction in axle bearings			Use hybrid bearings without seals.	X	
S.6.1-3 S.6.6-7	No interference between calipers and rims and vehicle body	S.7 Wheels S.8 Brake				X





Bringing the team together – the SE Wall



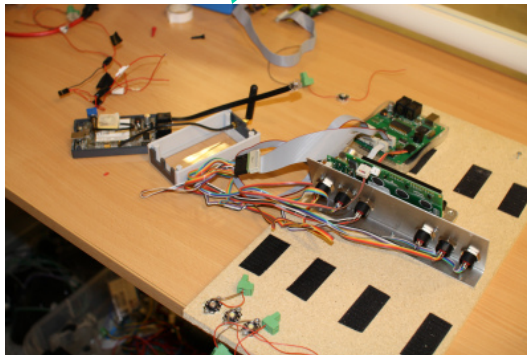


Monday	Tuesday	Wednesday	Thursday	Friday
Team Meeting -5 minute debrief -Week goals		5 Minute debriefing -CM		5 Minute debriefing -Problems -CM -Update

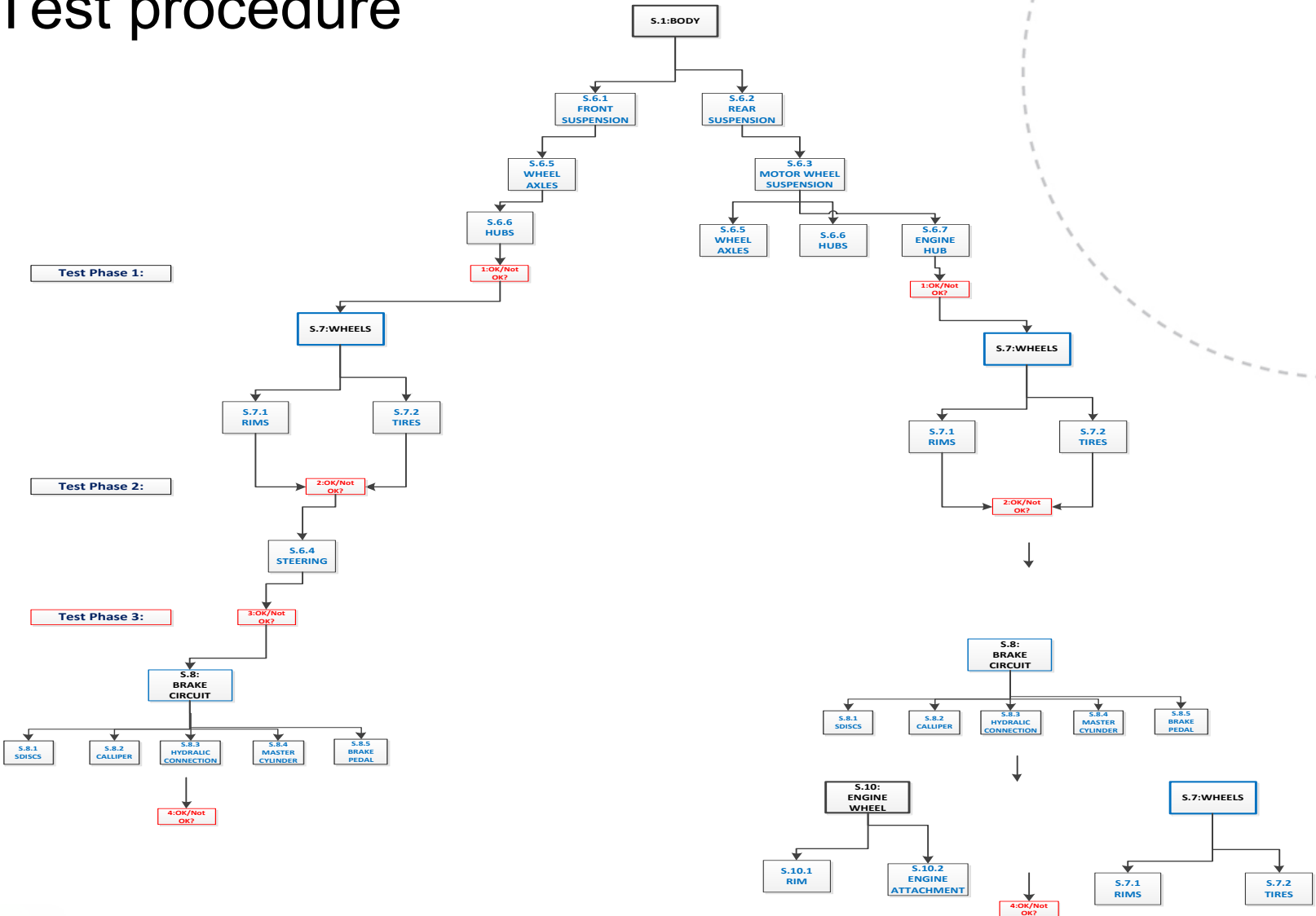


Testing and test beds

System	Test bed:
S.1 Body	Internal
S.2 Driver interface	Internal
S.3 Interior	Internal
S.4 Hydrogen module	External (Ballard)
S.5 Propulsion system	External (Smart motor)
S.6 Suspension	Internal
S.7 Wheels	Internal/External (Tevo Dekk)
S.8 Brake circuit	Internal
S.9 Control System	Internal
S.10 Engine wheel	External (Smart motor)



Test procedure



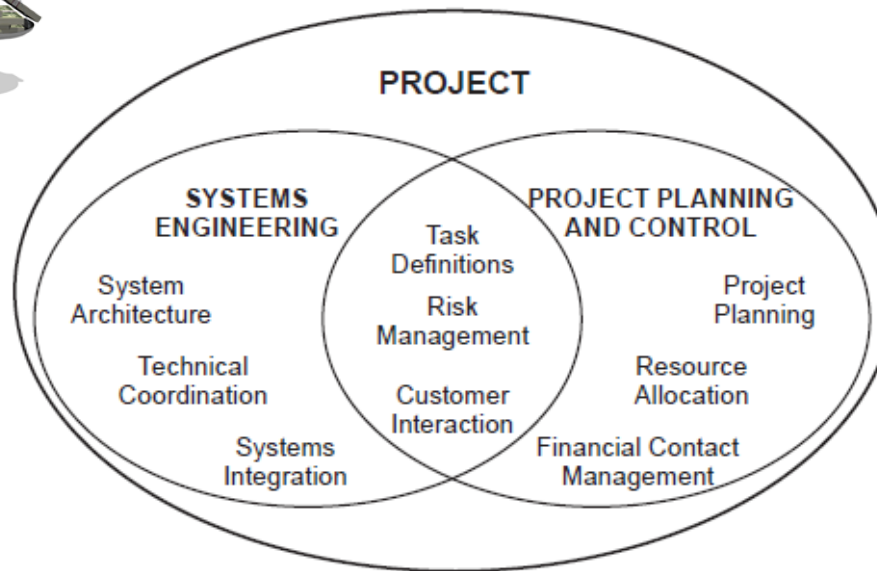


Figure 5-1 Project Management/Systems Engineering Overlap¹

Balance

Time management

Risk in all module documents



Goals achieved:

- SE
 - The use of SE methodology in a practical way
 - How does SE affect the project?
- Continuous improvement
 - Traceability through all documents; from requirements to the test results, and available as legacy for 2012
- Able to recruit 2 SE, more engineers (from 6 to 11), and early sponsorship for the 2012 team!





Team Photo / After

Systems Engineer Front and Center

Result: 1000 km/l in Shell Eco-Marathon 2011



Thank you

Q&A



Extra Slides



•Example: MEL(Master Equipment List) V.1

RTP Master Equipment list - Atla												
Product Info												
Description	Material	Equipment no:	quantity	Location	required for EFAT(10th October)	Required SIT(10th November 2001)	Comments	Action responsible	Action date	Suggested qty for purchase	OMM - Doc #	Spare parts list
WP04 - Wellhead tooling												
NA												
WP05 - XMT tooling												
TEST FIXTURE FOR MRT	1003638	new	1				RFQ	MD				
HANG-OFF TOOL, EMERGENCY, F/PROD TUBING	(10058033)10142475	?	1				Awaiting company approval to procure slick joint					
HANG-OFF TOOL, EMER DRILL PIPE 4 1/2 IF	(10062382)10142473	10456872	1	TRANDBY			Awaiting company approval to procure slick joint					
LIFTING TEST PLUG, 5 1/2 FH PIN, ASSY	10019618	new	1			1	RFQ	MD				
ASSY, TEST PLUG, 4 1/2 API F/PIN, 3/16	BB14-HS0002-17	new	1			1	RFQ	MD				
CASING ADAPTER F/THRT	BBJ36192A	10376357	1	MY		1	Marjan to ship	MA				
HANDLING & TEST TOOL, THRT, ASSEMBLY, SVT	BB11-200123-00	new	1			1	RFQ, check with availability at Tranby for SIT	HCS				
RUNNING TOOL TH, 18-3/4 10K SVTBT, ASSY	10019383	10278037	2			1	Marjan to ship 1st one, 2nd potentially switch with Trym 2) Verify with Marjan that nut on top of THRT is in place	HPØ 2) HCS				
HANDLING TOOL, FOR TH/ITC/BP	BBJ35230A	10404368 / 10558264	2	MY AND?		1	checked	MD				
VASHOUT TOOL TBG HGR AND SPOOL, ASSY	BB11-HS0002-34	10390758	1	AGOTNES		1	checked	MD				
TUBING HANGER HANDLING TOOL, 350 TON	BB11-HS0001-01	10456878	1	MY			Marjan to ship, make sure SRT is done once back in Ågotnes, Spanner to be placed on order	MD				
MECHANICAL TH & BP RECOVERY TOOL	10017251	10528856	1	AGOTNES		1	checked	MD				
THRT RACKING PROTECTOR, ASSY	10016290	new	2				RFQ					
STUMP, TEST FOR THRT WITH PASS THRU	10017774	10368632	1	MY			Marjan to ship	MA				
Sling set, THRT Test Stump	BB15-HS0001-67	new	1			1	RFQ					
CONTROL CPLR CHARGE, TEST TOOL, ASSY	10023324	10394219 / 10403913	2	AGOTNES		1	I haven't seen the second one	MD				
PLATE, SUPPORT, TUBING HANGER, ASSY	10030093	11202848	1	NEW		1	On order, send drawing through SWIMS to Total	MD				
TOOL, BP SETTING/UNSETTING, 5 KSI HYD V/P	10019613	10410199	1	AGOTNES			Verify physical location and condition	MD				
TEST PLUG, ASSY, 15K, BOP	10018823	wire-work the one from Mar	1	MY/NEW			Marjan to ship(MN:), request quotes from vendors for re-machining to Atla MN.	HCS				
GUIDE BUSHING, TUBING HANGER	10017968	11202849	1	NEW			On order, send drawing through SWIMS to Total	MD				
HANDLING TOOL, XT, 70T	10014224	10407051	1	AGOTNES			checked	MD				
TREE RUNNING TOOL, 18-3/4 15M, ASSEMBLY	10097308	10773460	1	TRYM?			1) Verify reduced testing scope at SIT 2) New MN for Hydraulic flying lead, arrange re-routing of lines with Ågotnes 3) Discuss with Trym/Oselvar project swap of TRT with REPSOL	1) HCS 2) HCS 3) HPØ				
TOOL, ISOLATION, TREE SPOOL, TEST TOOL	10019616	10403604	1	AGOTNES			Verify physical location and condition					



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•Example: MEL(Master Equipment List) V.2

B		C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
RTP Header Equipment List - 000																												
Description	Material	Serial no.	Equipment no.	Is Control	Qty	Location	Equipment Info			Maintenance code	RTP Equipment	EISSE and Equipment	Maintenance status	Vendor order reference	Branch order number	Estimated Serial No.	Estimated Serial Number if applied	Estimated value to location after RTV at end date for each maintenance	Action requested	Action CL	Integrated into new asset	Spare parts list	RTP ID and location	Internal comment				
							Equipment ID	Equipment ID	Equipment ID																			
RUNNING TOOL, 16.5/4 18K 5787, ASV	1881581	438118102-188-1	1887441	Y	1	Asheville							VOIR is assigned equipment will have 7887 by the date.	X 7887 Tool will have 7887 by the date.	4381181		12.12.2011		Major M									
HANDLING TOOL, FOR T/IC/PC	94-152386	11616-1	1881824	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381812	4381168	18.12.2011		CR									
HANDLING TOOL, FOR T/IC/PC	94-152386	11616-1	1881818	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TUGWART TOOL TUGWART AND SPOONAGE	94-152386-14	11616-1	1881818	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
HANDLING TOOL, HANDLING TOOL, 16.5/4 18K 5787, ASV	94-152386-14	11616-1	1881818	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
Mechanical Tool Recovery Tool	1881581	438118102-188-1	1881818	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
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TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
TRUCK BACKING PROTECTOR, ASV	1881581	438118102-188-1	11616-1	Y	1	Asheville							2, 800 Tool of Office available.	2, 800 Tool of Office available.	4381818	4381168	18.12.2011		CR									
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- Requirements added to every tool:

- Lifting certification
- NDT certification
- Torque reports
- Maintenance need

- Visual status

- Offshore phases

