INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Keep Systems Engineering Simple to Get the Job Done

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Agenda

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- Introduction to Shell Eco Marathon
- Challenges in SEM Product Development
- System Engineering in 2012 SEM team
- SE Examples from 2012 SEM team:
  - Lean Product Development
  - Model-Based Systems Engineering
  - Knowledge Capture and Transfer
- Conclusions
- Outlook

Shell Eco Marathon

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- Worldwide student competition in designing, building and testing energy-efficient vehicles
- Goal: Go the furthest distance using the least amount of energy
- Race in Rotterdam each May

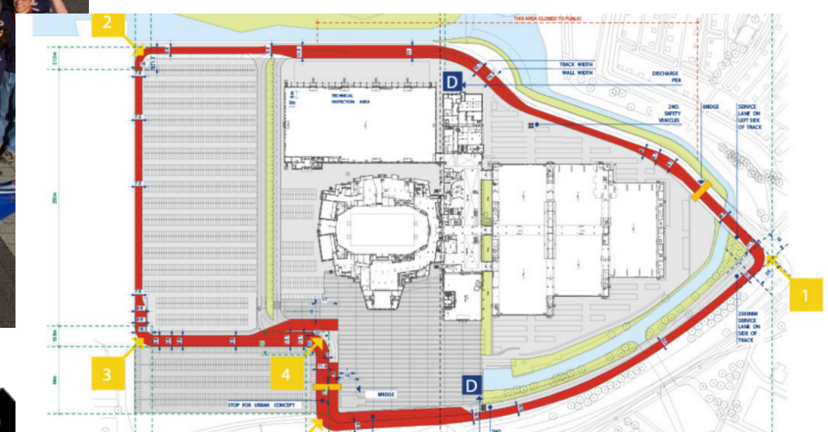

Figure: The race track La Hoya in Rotterdam, Netherlands.

NTNU Student Team 2012

International team of 14 students in the disciplines:

- project management
- mechanical engineering
- cybernetic engineering
- electrical engineering
- industrial design
- media and communication
- systems engineering

DNV Fuel Fighter

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2008:

Pure Choice

2009-2011:

DNV Fuel Fighter

2012-201X:

DNV Fuel Fighter 2

NTNU participates since 2008 in Shell Eco Marathon Europe, Urban Class

NTNU team added a Systems Engineer in 2011

New development in 2012, the first time in Battery Electric Urban Class

Challenges in SEM 2012

- First team that competes in battery electric class (prior fuel cell class)
- Higher technical risk in new development versus improvement project
- 14 team members (only 6 in SEM 2011 team)
- (new) knowledge needs to be captured and transferred to coming team generations

Research questions:

- How can team members ensure easy and effective communication?
- How can knowledge be captured effectively and (re)used in the next team generation?
- How can knowledge be structured ensuring a clear and simple overview?
- Is systems engineering a discipline or an attitude?

SE activities in SEM 2012

Approach: Use 2 System Engineers

SE1: Verification, validation and testing

SE2: Visualization, modeling and lean methods

Main system engineering activities in SEM 2012

- Stakeholder Analysis
- Implementation of visual board with milestones, decision gates, etc.
- Risk mitigation activities
- VVT activities
- Establishment of SE models, including a hierarchical architecture use to track allocations to requirements and team assignments
- Efforts to define and implement effective knowledge documentation and capture

Stakeholders in SEM

- Stakeholder analysis:
  - The current team
  - Driver: Real and immediate needs for safety (also SE1)
  - Sponsors: Draw attention to the project in popular media and non-engineering PR activities
  - Future SEM teams: ultimate users as they are the ones inheriting the vehicle

SEM 2012 team

SEM 2013 team

Lean Product Development

- Has its origin from lean manufacturing (Toyota Production System) but is different due to the fundamental dissimilarities between production and product development
- The three dimensions of LPD :
  - Reduce cost through minimizing waste
  - Reduce time-to-market
  - Improve quality and product innovation (influence price)
  - ➢ Create maximum customer value (1st principle)

- *Value (in PD):* any activity that transforms a new product design in a way that the customer is both aware of and willing to pay for; i.e. activities that mitigate risk.
- *Waste*:
  - Type 1: activities that do not create value, but are necessary to enable value generation (e.g. administration, coordination,…)
  - Type 2: pure waste (e.g. waiting, underutilization of people,…)
- Value creation can also be assigned to the second value stream: **Knowledge**

A3 Documentation

- Continuous improvement and learning cycles are important part of LPD
- Knowledge capture and reuse need to be efficient
- Knowledge is an important resource for risk mitigation and prevention of repeated problem solving

An *A3-report* is a common type of *Knowledge-brief*, with aim to visualize problem, goal, process, solutions, and risk elements in a standardized form.

7 important elements of A3 thinking:

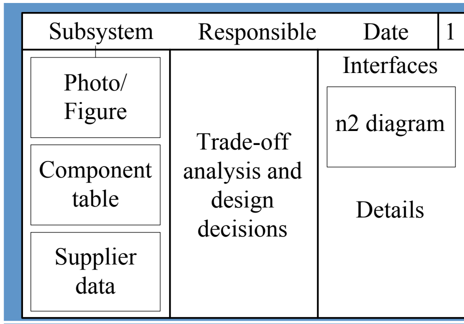
- Logical thinking process
- Objectivity
- Results and process
- Synthesis distillation and visualization
- Alignment
- Coherence within consistency across
- Systems viewpoint

2 dimensions of knowledge:
tacit and explicit

A K-brief encourages the engineer to express tacit knowledge and turn it into explicit knowledge

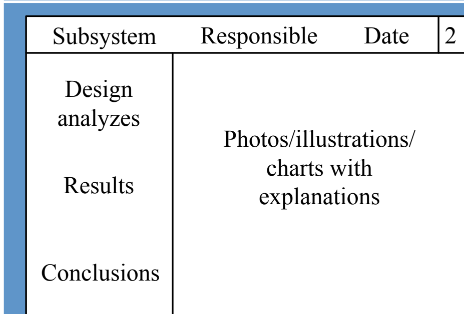
3-page K-brief

A3 layout

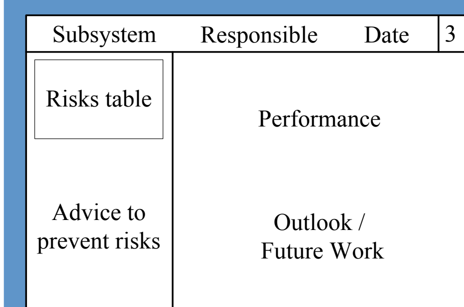


Content

- Figure of the subsystem
- Component table
- Manufacturing methods
- Trade-off curves
- Design decisions
- n2 interface diagram
- Details about interfaces and dependencies



- Engineering Design
- Design Analyzes
- Visual design description
- Critical design review



- Risks
- Risk evaluation
- Advice for risk mitigation
- Performance report:
  - Verification
  - Validation
  - Testing
- Advice and suggestions for future work

Example: Body, page 1

S.1 Body Petter T. Larsen/2012

DNV FUEL FIGHTER 2

Component		Material	Dimensions [mm]	Pro-cured	Satis-faction [%]
S.1.1	Monocoque	CF		NPD	90%
S.1.2	Driver Door	CF		NPD	70%
S.1.3	Side covers	CF		NPD	90%
S.1.4	Lights	PC		NPD	70%
S.1.6	Horn	Steel		R	90%
S.1.10	Back Hatch	CF		NPD	90%
S.1.11	Stop Button			P	80%

NPD = new product design, R = reused part, P = purchased part

Supplier data

- Monocoque, door and hatch produced in Fredrikstad. Mold material delivered from Jackon (sponsored) (EPS, Jakopor) and Svas Kjemi (28,000 NOK) (epoxy paste, p25), milled at Eker Design (40,000 NOK + sponsored). Produced at High Performance Composites (10,000NOK + sponsored)
- Side covers produced in-house with left over material from production of monocoque. Carbon fiber delivered by Devol, epoxy and hardener (High Performance Epoxy) deliverd by Re-Turn (sponsored)
- Lights produced in-house at IPD with material delivered by IPD.
- Stop buttons ordered from Elfa.

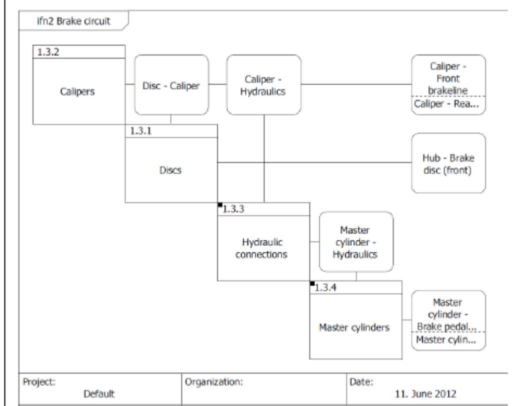
- HPC:
- Jakon:
- Eker Design
- Svas Kjemi
- Re-Turn:

Trade-off analysis/important decisions

The most important decision was to make a light weight, robust and aerodynamic car body. This was achieved by using a monocoque structure made of carbon fiber. Other structural principles were never considered since this would have resulted in a heavier car. But, different production methods were considered.

Prepreg production method would have created a lighter car, but due to sponsors available, production cost and materials for molds and production, vacuum infusion was chosen.

Interfaces



Example, Body, page 2

S.1 Body Petter T. Larsen/2012

DNV FUEL FIGHTER 2

Analyses

Background

Requirements

- Low aerodynamic drag
- Low weight
- Strength
- Durable

Software used

- UGS NX 7.5 Advanced simulation, strength analysis of monocoque
- ANSYS CFX, Flow analysis of monocque assembly

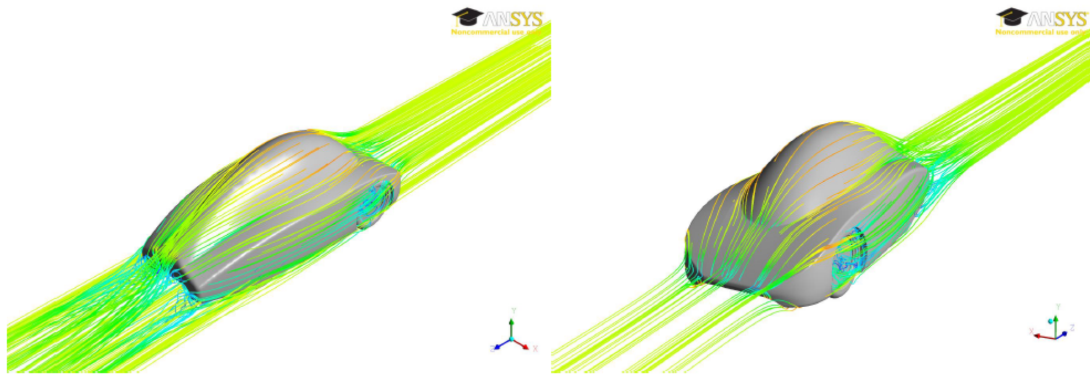
Results

- Computed aerodynamic drag: 0.17, wind tunnel: 0.19
- Wheight: 30 kg, fully assembled

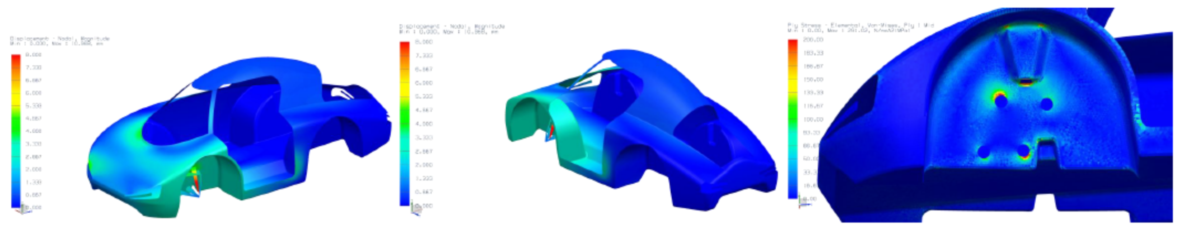
Conclusion

The exterior has very good aerodynamic properties, also verified by wind tunnel testing. The layup configuration used on the car resulted in a very robust and durable car, which can withstand loads during driving on uneven ground. Still, the exterior has maintained low weight.

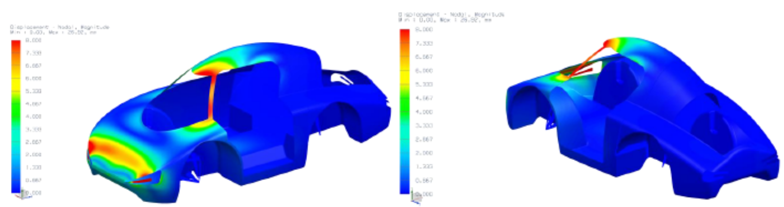
Streamline plots from ANSYS.



Displacements due to loads in the wheel well, bump and cornering. Stresses in the wheel well.



Displacements due to loads stated by the rules.



Example, Body, page 3

S.1 Body   Petter T. Larsen/2012

DNV FUEL FIGHTER 2

Identified risks

Description	L	C	LxC	Mitigation
Fracture	2	3	6	Reinforce with aluminium plates and glue
Door failure	3	3	9	Aluminium plates or tape
Horn malfunction	3	2	6	Use spare
Misalignment	3	3	9	Realign, tape
Side cover failure	3	2	6	Use tape

L = likelihood, C = consequence

Performance

During assembly, all part of the monocoque was constantly checked for alignment and placement to ensure a perfect fit. This resulted in nice and smooth transitions between body and side covers, door and back hatch.

The monocoque was tested without doors and side covers at Dragvoll parking lot. The wheel wells coped with the loads from the suspension system and no wear or cracks were discovered.

During race the monocoque performed very well. The stresses from testing and racing din not affect the monocoque structure. However, the topside of the door came loose during in high speed in one test run and was fixed using double sided tape. During the race, this happened again due to rain had softened the tape. The tape was a sufficient solution, and was used for the rest of the race. A more permanent solution should be investigated with a locking mechanism or with the use of brackets. A stiffer door will also solve this problem. The back door and side covers performed very well during the whole competition and no problems occurred.

The back door lost it shape on the way home, due to high temperature in the sun.

Proposed future work

- Make a more permanent solution for fixing the topside of the door to the monocoque
- Make front wheel covers to reduce drag.
- Realign the back door, heat it up, and fix it in the desired shape.
- Realign the door

Visual Product Models (MBSE)

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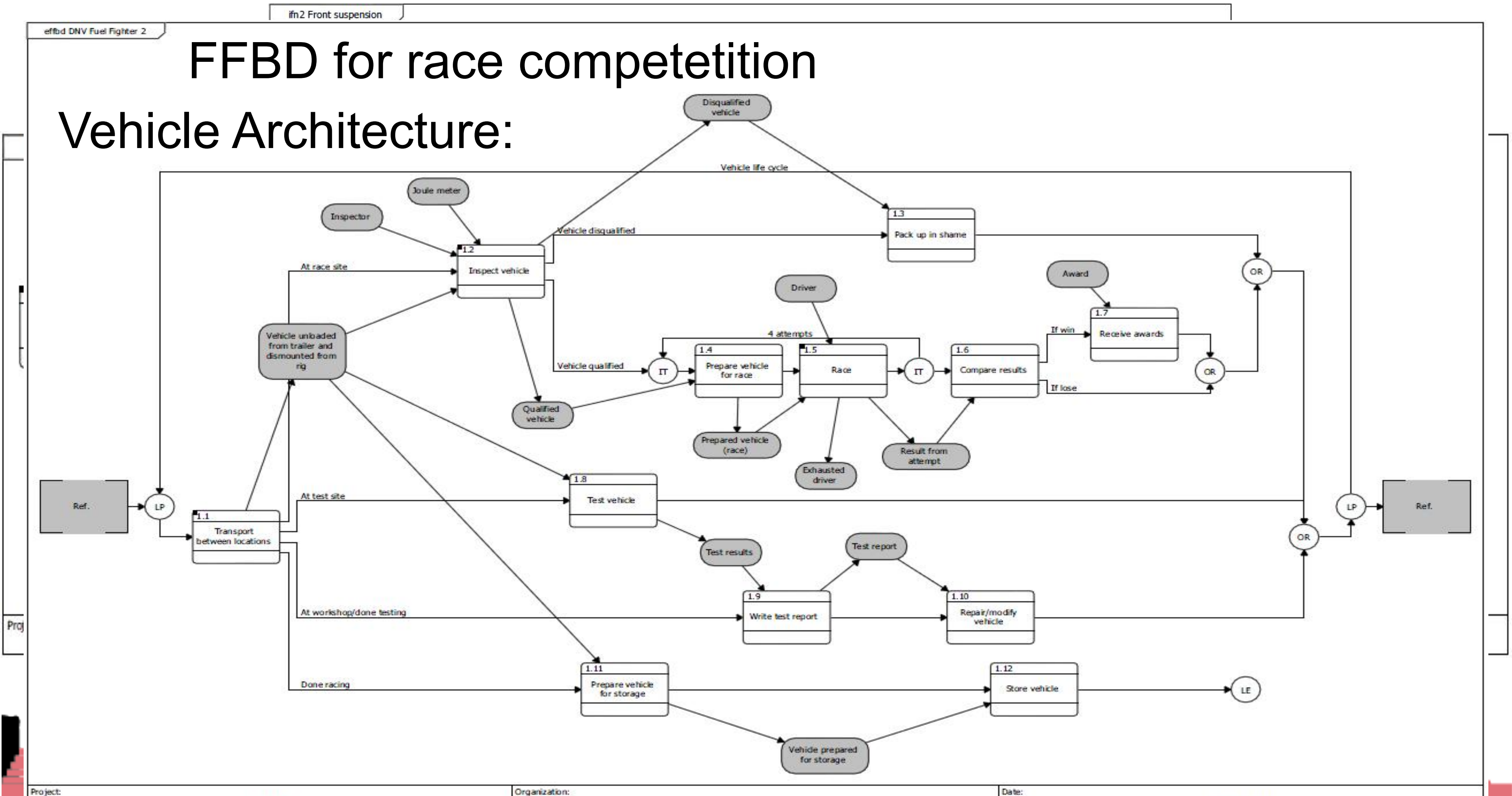
- Requirements, functional analysis, architecture, interface design and subsystems have been modeled in CORE8

FFBD for race competetition

Vehicle Architecture:



Discussion 1

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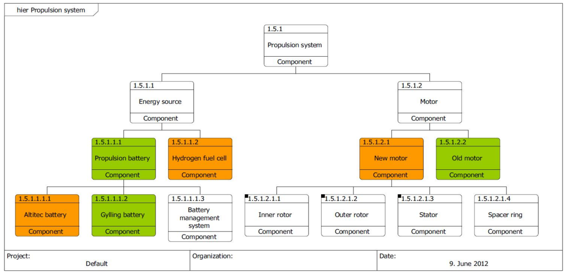
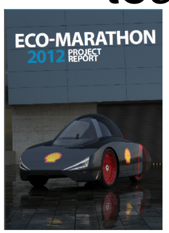
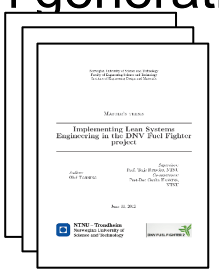
- How can team members ensure easy and effective communication?
  - Include all principal solutions (both chosen and <u>not</u> chosen) in architecture documentation
  - Color coding in SE-models to make design alternatives transparent
  - High visibility makes design evaluations easier



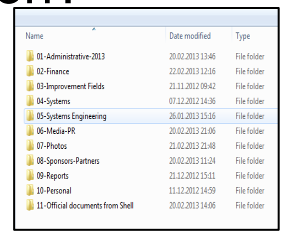
- How can knowledge be captured effectively and (re)used in the next team generation?



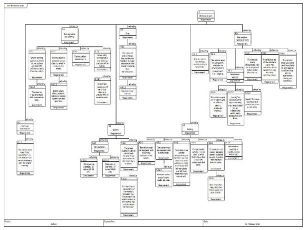
Project Report



Master Theses



File structures



SE-models

K-briefs

Former team(s)

Discussion 2

- How can knowledge be structured to facilitate clear and simple overview?
  - K-brief appears to be an easy way of presenting information but needs to be put into the right context
  - Template necessary to save time (both in reading and writing)
  - Knowledge-culture around them needs to be established
  - Much of the K-brief documentation was done by a systems engineer, which meant more work for him/her and a «detour» of knowledge flow
- Is systems engineering a discipline or an attitude?
  - Some team members show a tendency towards perfection of parts instead of the performance of the whole system
  - Project manager found SE helpful
  - The systems engineers discovered that it is important to be flexible
  - People feel SE very useful when problems arise

What happens next?

SEM 2013 team will execute continuous improvement of the car

- Increase the number of K-briefs and link them to the architecture
- Knowledge capture at certain points
- Implementation of knowledge wall with A3s or post-its

Further challenges:

- Keep SE and documentation effort as low as possible
- Establish a culture with routines for knowledge sharing and transfer
- Quality control and maintenance of documentation

Thank you for your attention!

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