MBSE for Engineering Students

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The situation

- The first author participated in the Systems Engineering Curriculum Working Group of INCOSE. This international working group met through several teleconferences during 2006.

- The group determined that the industry requires new systems engineering competencies from engineers mainly those related to system concepts, architectural design, and modelling and simulation

The IAEI program

- The IAEI is two years specialization program created for bachelor engineers from different engineering specialities to acquire competencies for working as professional engineers in industrial automation and robotics applications.

- The main topics addressed in the IAEI program are those related to control theory, electronics and software engineering.

Systems engineering at the IAEI program

- Project engineering, project management and fundamentals of systems engineering are addressed as well in a course called "Project engineering and management."

- This course is a 60 hours of theory and practice course where theory (24 subtopics including systems engineering, facilities engineering and project management) is combined with a realistic case study to be developed by the students working in groups of five persons.

Final degree work

- The program final degree work ranges from 600 to 900 person hours of effort.

- The scope and application of the work is chosen by the student and his/her project advisor.

- The projects are related to the topics of the program, so the students projects presented are diverse from electronics projects to software development projects, and industrial control and robotic applications as well.

Systems Engineering (I)

- When a student chooses a project involving systems engineering, the main focus is placed on the preliminary design of a complex system, not in the detailed design.

- Issues as requirements engineering, functional architecture and physical architecture are considered as part of the project scope, so the main student project deliverables are related to them

Systems Engineering (II)

The main issues considered

- Functional architecture is the core model
  - Difficulty: the distinction between subfunctions and functional dependency
  - Difficulty: to obtain functional requirements from the functional model
- Non functional requirements→ Diverse quality models
- Interfaces → How to deal with them
- The bridge to the software architecture → Responsibility driven design

Why MSBE?

We need a new paradigm to develop complex products. This paradigm is Model Based Systems Engineering where models are used as an integral part of the system technical baseline.

- the primary artifact is an integrated coherent an consistent system model

- all other artifacts are generated from the system model

- All diagrams are merely views of the system model

The three pillars of MBSE

- A modeling language or modeling notation
- A modeling process
- A modeling tool

The ISE&PPOOA process

How to develop a software
intensive system from the system
to its components

ISE&PPOOA in a nutshell
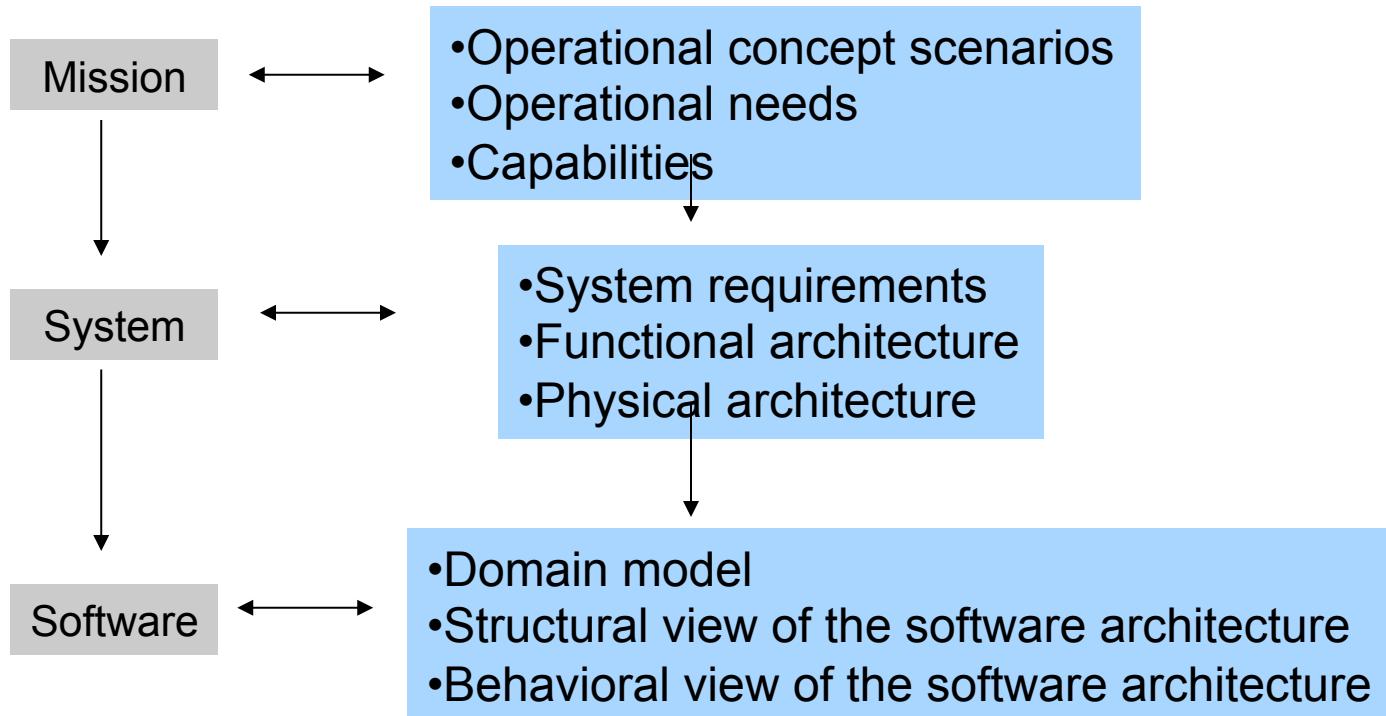
Mission

- Operational concept scenarios
- Operational needs
- Capabilities

System

- System requirements
- Functional architecture
- Physical architecture

Software

- Domain model
- Structural view of the software architecture
- Behavioral view of the software architecture

Systems engineering

ISE subprocess

The ISE subprocess

- The main goal is the creation of the functional and physical architectures of a system identifying the subsystems and their interfaces.

- SysML notation is used

- The system may have subsystems software intensive and/or non software intensive where Physics conservation laws of mass, energy and momentum are an important issue that should be considered when representing the system views.
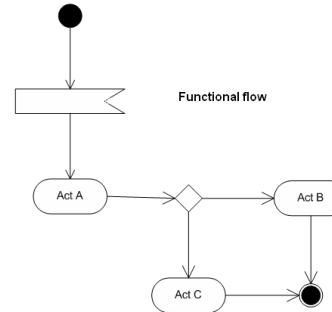
The ISE subprocess
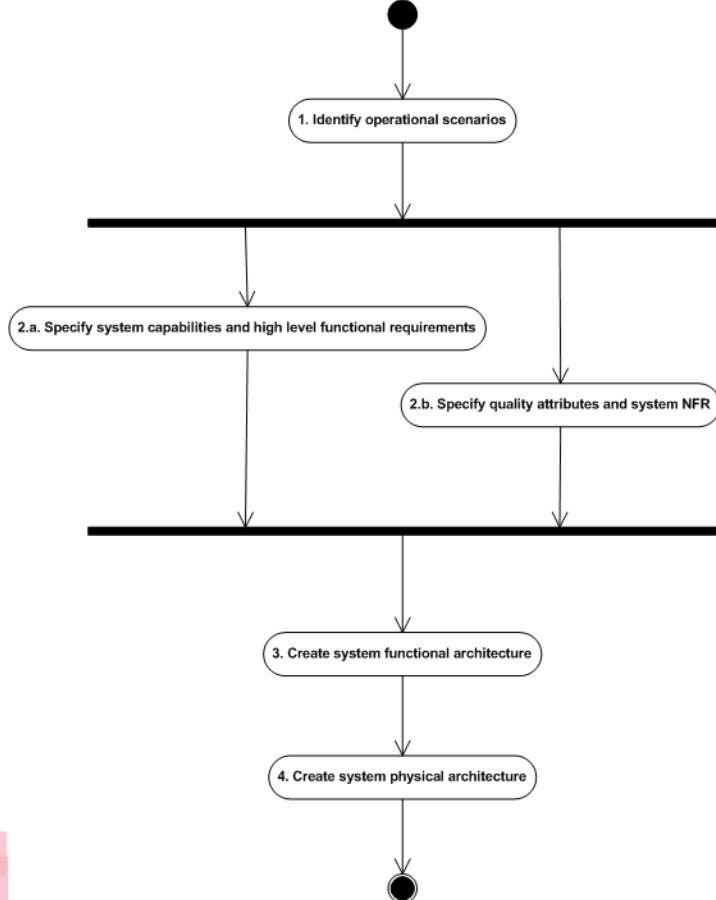
Functional architecture

Functional Hierarchy
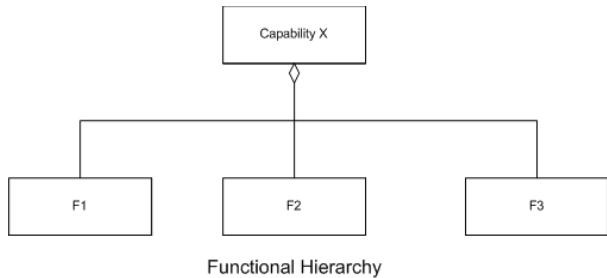
Función (F1)	F1->F2	F1->F3	F1->F4	F1->F5
F2->F1	Función (F2)	F2->F3	F2->F4	F2->F5
F3->F1	F3->F2	Función (F3)	F3->F4	F3->F5
F4->F1	F4->F2	F4->F3	Función (F4)	F4->F5
F5->F1	F5->F2	F5->F3	F5->F4	Función (F5)

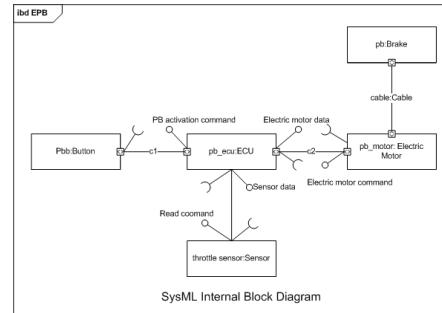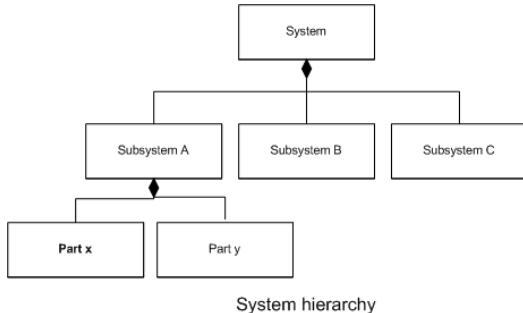**Functional interfaces**

Functional flow

If ALTITUDE is greater than TRANSITION
   ALTITUDE, then:
   set SPEED to MACH,
   otherwise
   set SPEED to AIRSPEED.

Funtion specification

Physical architecture

System hierarchy

SysML Internal Block Diagram
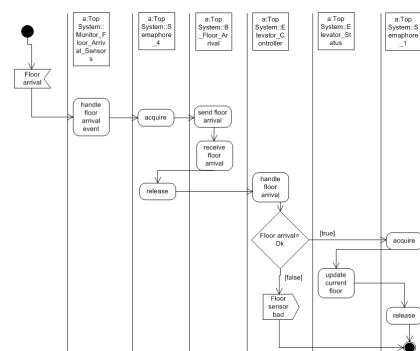
Activity diagram with swimlanes

| Name	Central fuel tank
Description	Fuel tank which delivers the fuel to the propulsion subsystem through the control valve of this tank. The fuel pump propels the fuel to obtain the mix together with the air coming from the environment. Finally the mix flows to the propulsion subsystem
Prov Interface	▪Fuel (from the Control Valve of the Auxiliary Fuel Tank located in the Wing to the Central Fuel Tank)
Req. Interface	•Fuel (to the Fuel pump) •Fuel Level (to the Central Fuel Tank Sensor) •Waste (to the Central Fuel Tank Drain Valve)

Part description

Software

PPOOA architectural framework

PPOOA

- A framework for architecting software intensive real-time systems
    - Based on UML notation
    - Describes the system architecture using two views that may be supported by several diagrams; one view is the static or structural representation, and the other view is the dynamic or behavioral view of the system. The behavioral view is represented by modeling the system responses to events.
    - Supports a diversity of components and coordination mechanisms (for synchronization and communication) not found in UML.
    - Provides a tool agnostic architecting process (PPOOA_AP), defining the steps to build the architecture

The PPOOA subprocess
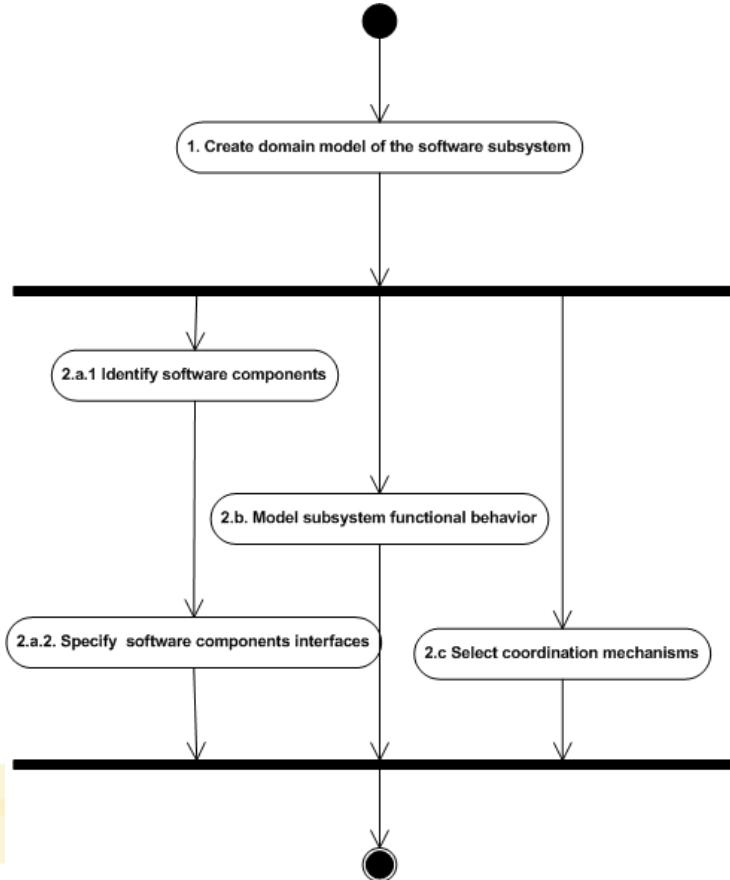
# An example of MBSE final degree work

How to engineer a rescue robot
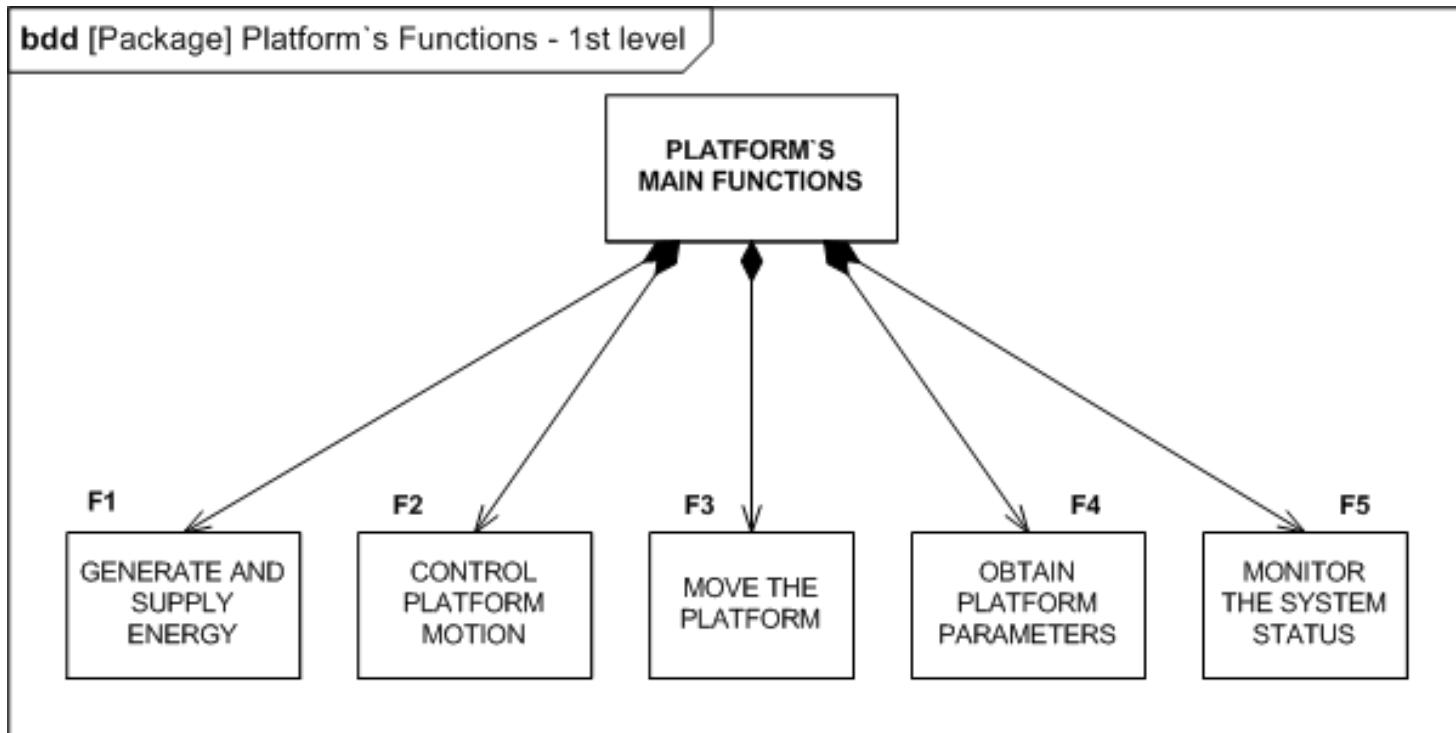
Mission related deliverables

- The deliverables related to the mission dimension are the mission use cases represented as a use case diagram and their scenarios represented in tabular form

- From the mission scenarios, 128 operational needs were identified. As an example the operational need ON1 that is related to the emergency response team is presented here:

  – ON1: "The maximum weight of the robotic system shall be less of 25 Kg to facilitate its transportation by its operator".

Use cases diagram
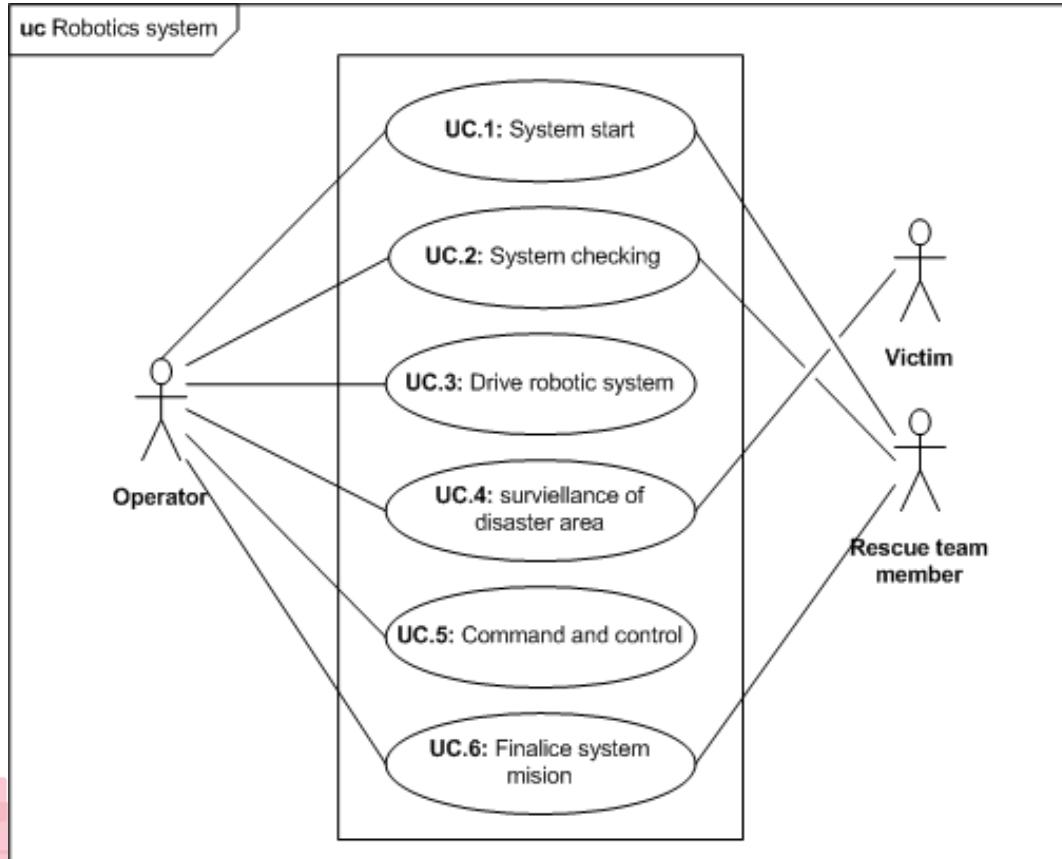
Main functional capabilities
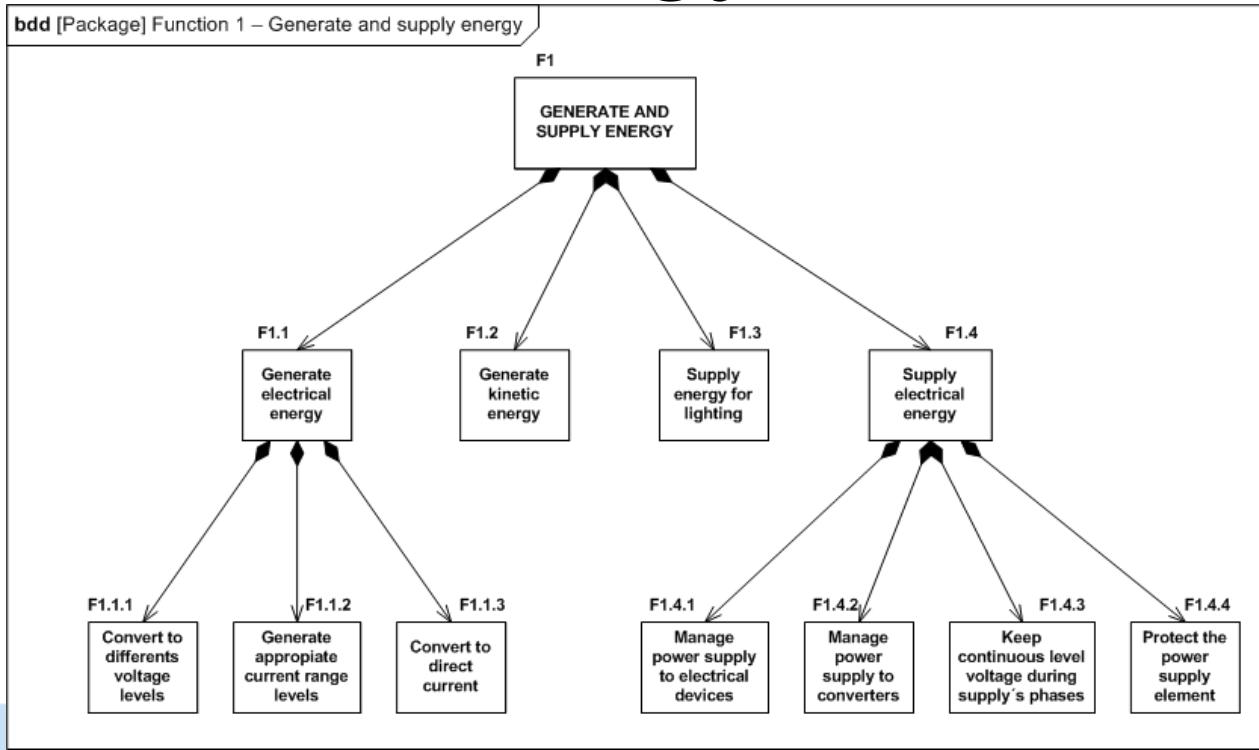

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System related deliverables (I)

- The deliverables related to the system dimension are the system requirements, functional architecture and physical architecture

- 154 system requirements were identified, tagged and specified in textual form

- Next slides represent the functional hierarchy of F1 "Generate and supply energy function" and the N^2 chart the functional interfaces of its subfunctions including external inputs an outputs.

F1. Generate and supply energy

Functional interfaces of "Generate and supply energy"

| - Input electrical parameters - Emergency Stop signal - Control signal for switches	- Movement control signals - Power variation order for main engines - Power variation order for auxliar engines	- Light control signal - Light variation order	- Turn on signals - Turn off signals	System Inputs System outputs
F1.1. GENERATE ELECTRICAL ENERGY			- Power supply for electrical elements - Power supply for mechanical elements	
	F1.2. GENERATE KINETIC ENERGY			- Temperature generated - Mechanical engine powers
		F1.3 SUPPLY ENERGY FOR LIGHTING		- light - Emergency lights
- Electricity for electrical elements	- Electricity for mechanical elements	- Electricity for electrical elements	F4. SUPPLY ELECTRICAL ENERGY	- Electricity for other subsystems

# System related deliverables (II)

- The physical architecture is represented by the system decomposition into subsystems using a SysML block definition diagram

- The subsystems diagram is complemented with SysML block definition and internal block diagrams for each subsystem.

- A textual description of the subsystem blocks is also provided in the final degree student document

- A SysML parametric diagram or a Matlab diagram that may be run for simulation purposes supplements them
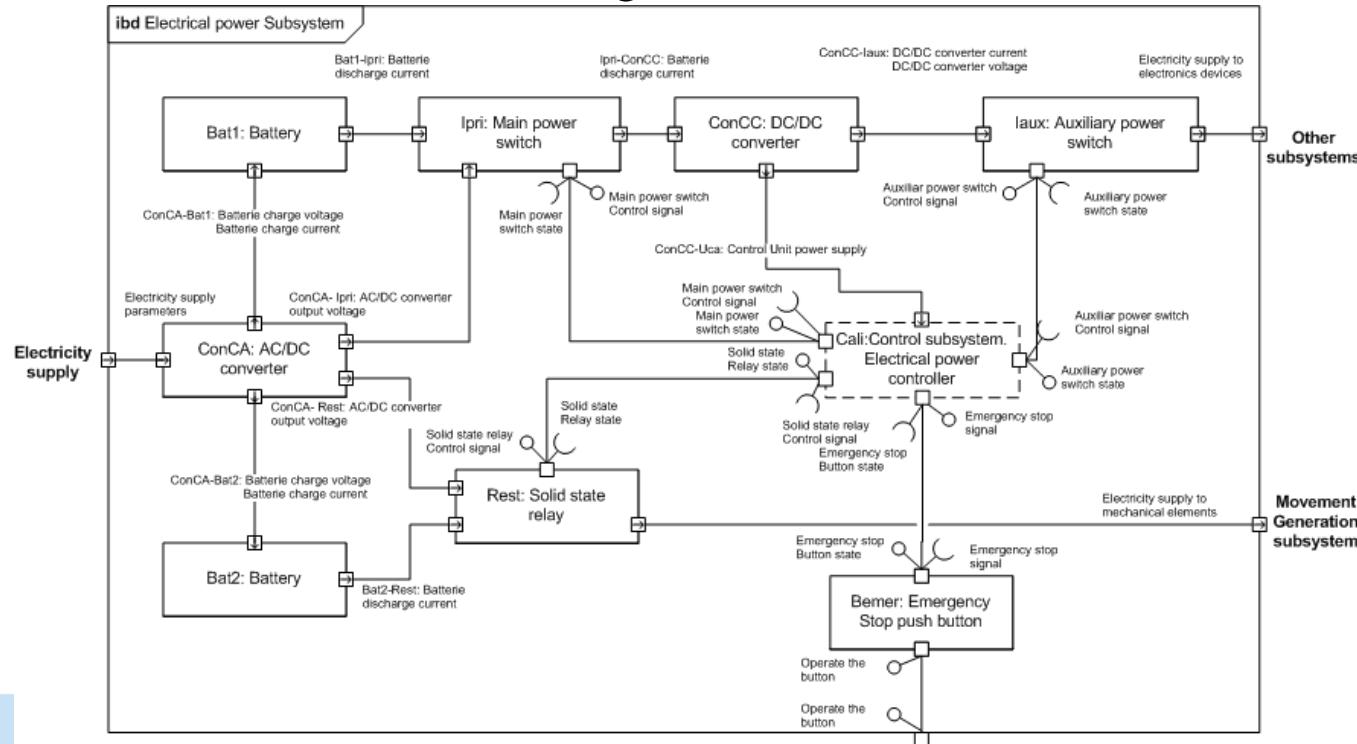
Main subsystems
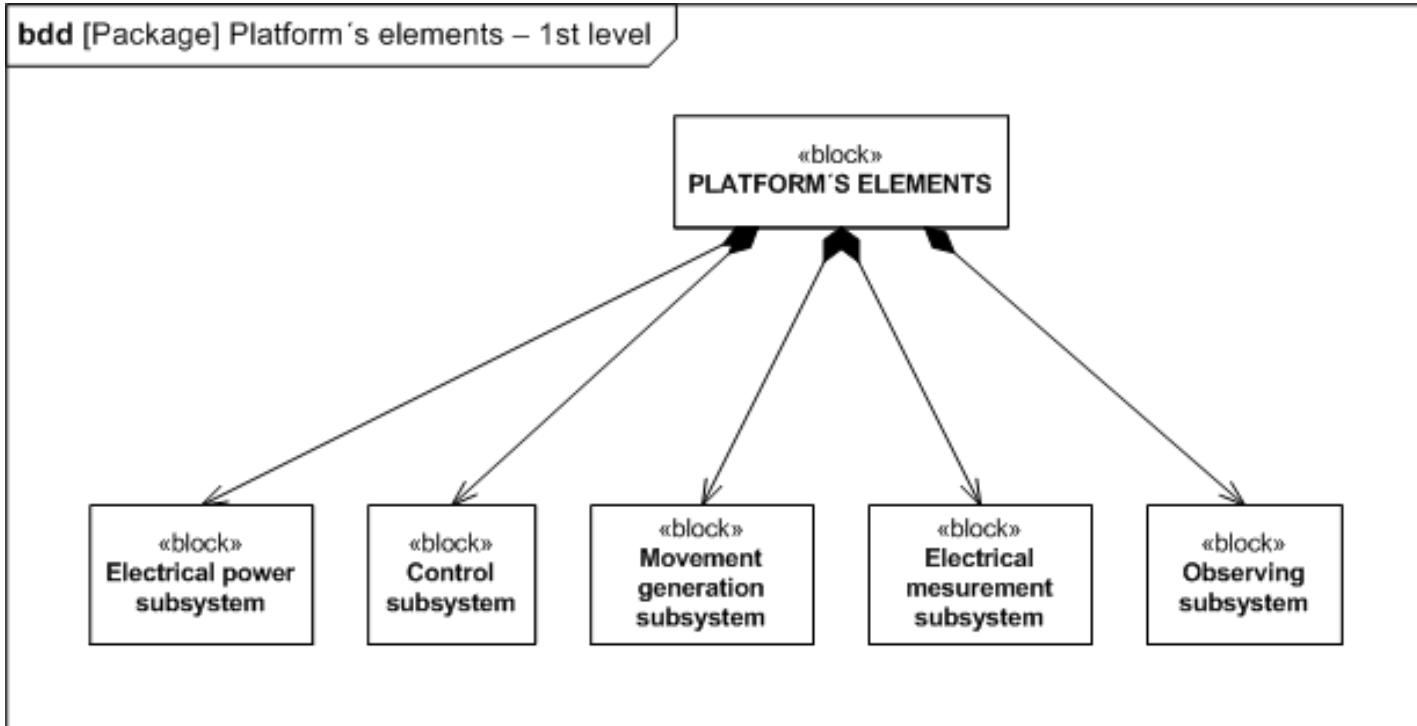
Electrical power subsystem
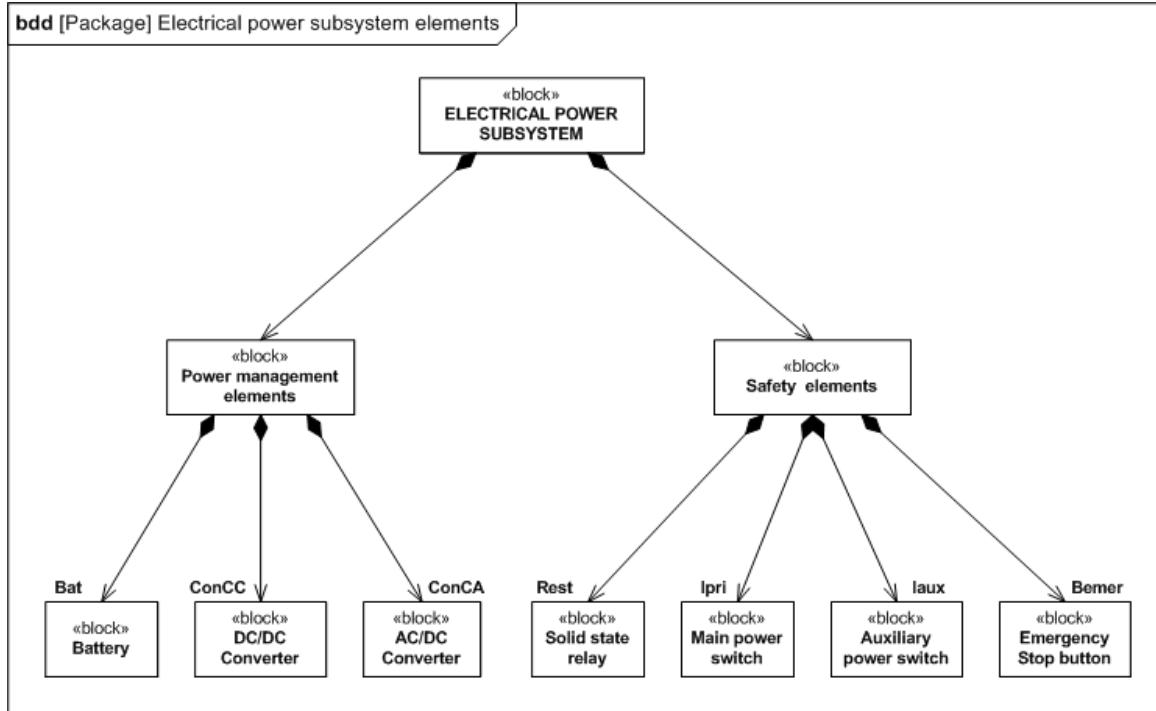
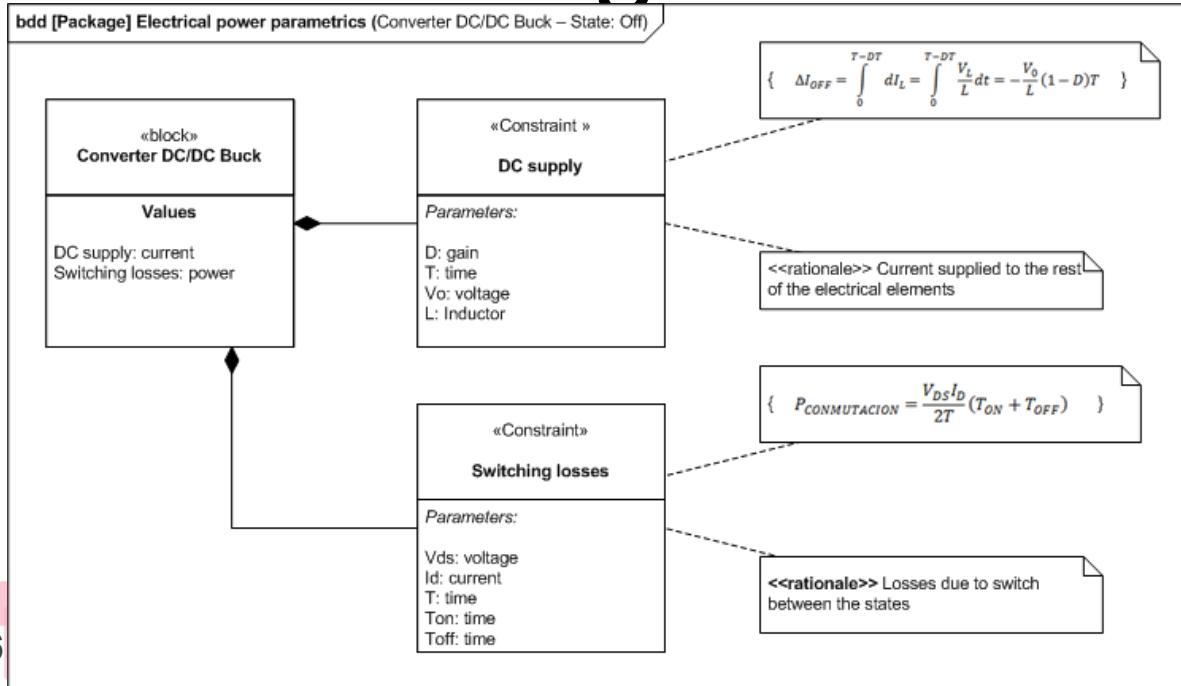# IBD of the electrical power subsystem

Converter DC/DC Buck parametrics context block definition diagram

To conclude

- The use of a process facilitates the learning and application of MBSE

- The scope of the Project presented was the preliminary design of a rescue robot and it encompassed the realization of 26 Block Definition Diagrams, six Internal Block Diagrams, one for each subsystem modeled, and three Parametric Diagrams

- The scope of the system models represents 255 system functions and 110 physical blocks.

- The student effort limitations difficult the complete engineering of all of the subsystems but this obstacle is an opportunity to other students to continue the previous work and engineer the incomplete subsystems where they have more domain knowledge or experience

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