

**Systems of Systems Complexity Set**

coordinated by  
Jean-Pierre Briffaut

Volume 3

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# **Model-based Systems Architecting**

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*Using CESAM to Architect  
Complex Systems*

Daniel Krob

Color Section

Type of system	Characteristics	Typical example	Design Strategy
<i>Product component</i>	Does not exist independently of a product	 Aircraft engine	V-cycle
<i>Integrated product</i>	Strong coupling of fixed components	 Aircraft	W-cycle
<i>Systems of systems</i>	Weak coupling involving moving components	 Airport	Interfaces standardization
<i>Ecosystem</i>	Interactions involving moving components	 Air Traffic Management	Actors Influence

**Table I.1.** *Categories of engineered systems*



**Figure I.1.** *Mont Blanc from Chamonix (1,200 meters above sea level)*



**Figure I.2.** *Mont Blanc from the Black Lake  
(2,000 meters over the sea)*



**Figure I.3.** *The socio-technical dimension of systems*



Figure I.4. A complex component system: a computer system

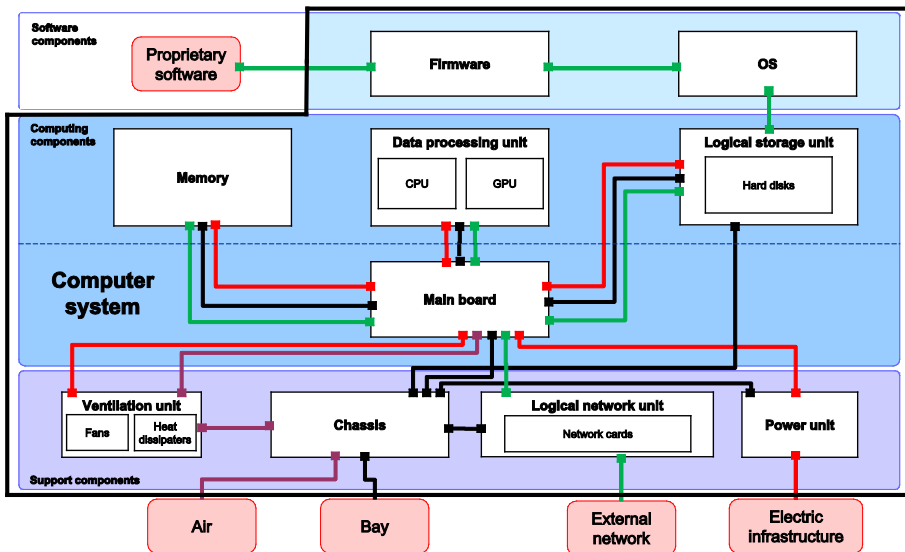
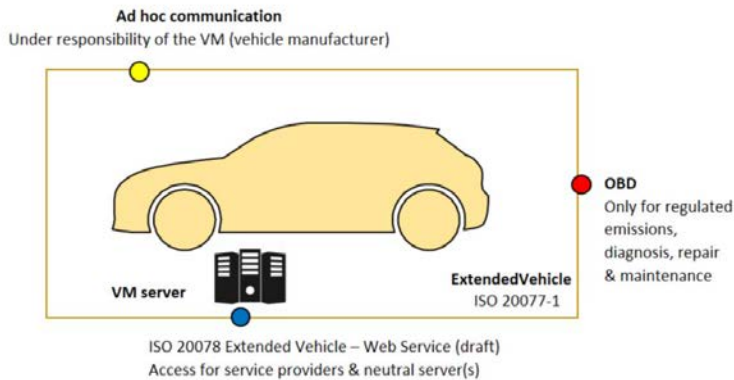
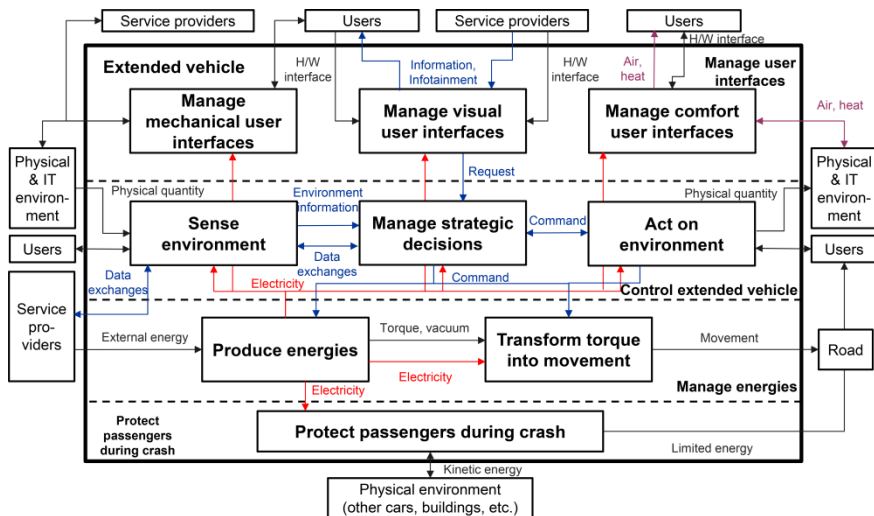


Figure I.5. Constructional interaction diagram of a computer system

## Extended vehicle



**Figure I.6.** *An integrated product system: an extended vehicle*



**Figure I.7.** *Functional interaction diagram of an extended vehicle*



**Figure I.8.** *A system of systems: the railway system*

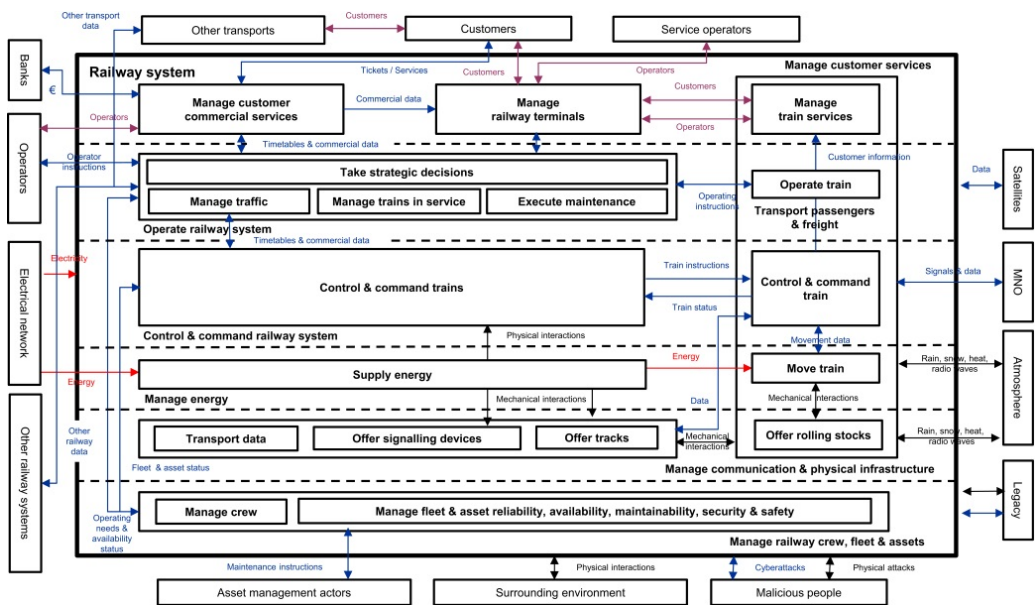


Figure I.9. Functional interaction diagram of the railway system

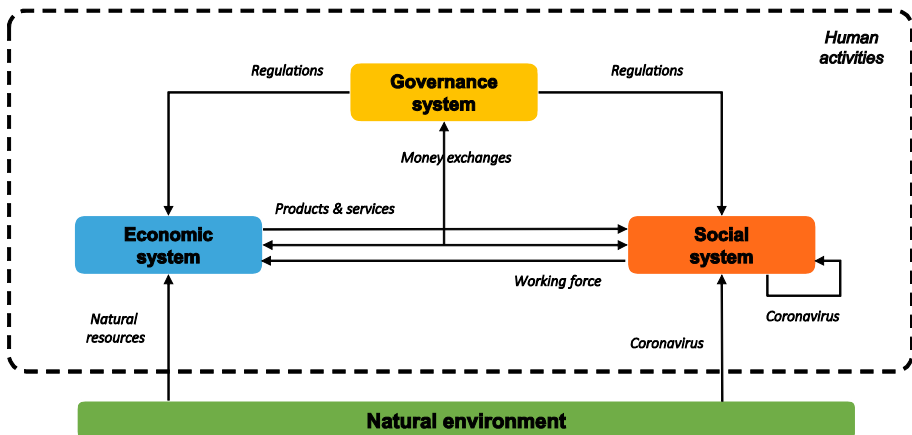
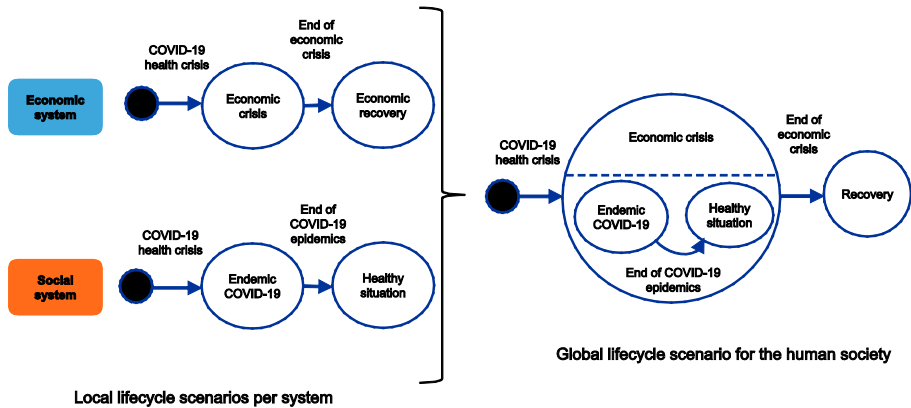
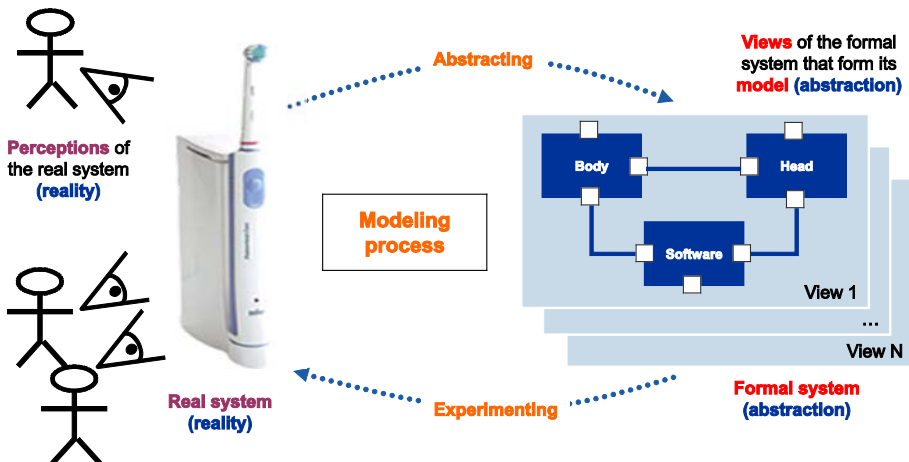


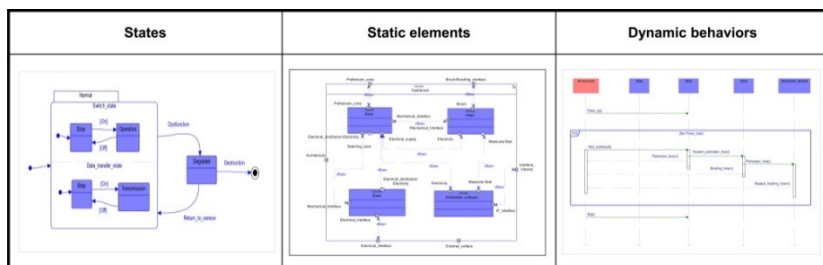
Figure I.10. An ecosystem: the world as a system



**Figure I.11.** Illustration of a standard process for constructing a COVID-19 global lifecycle scenario



**Figure 1.1.** The two abstracting/experimenting sides of a system modeling process



**Figure 1.3.** Structure of a standard complete system specification



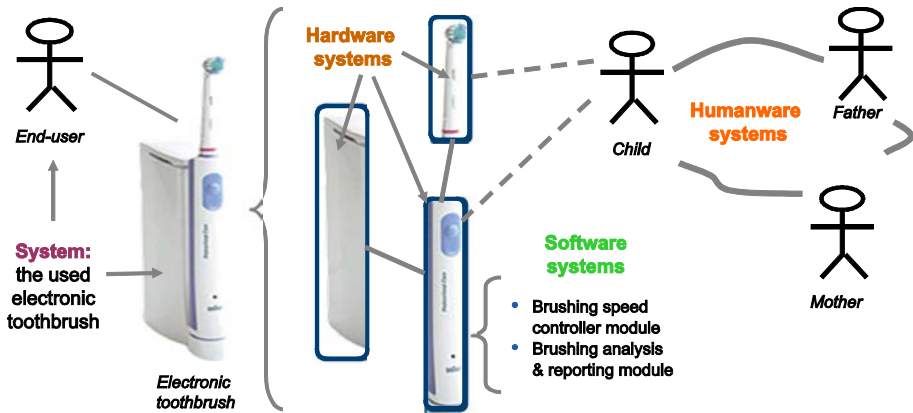


Figure 1.5. Example of an integrated system: the used electronic toothbrush

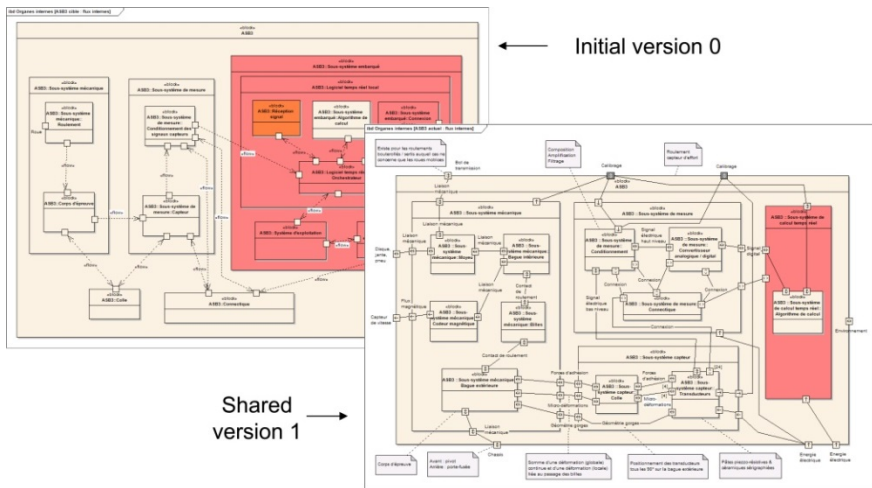
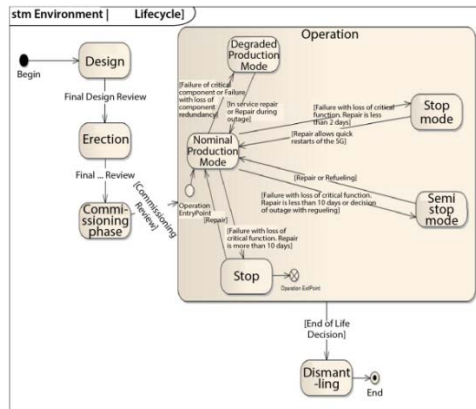
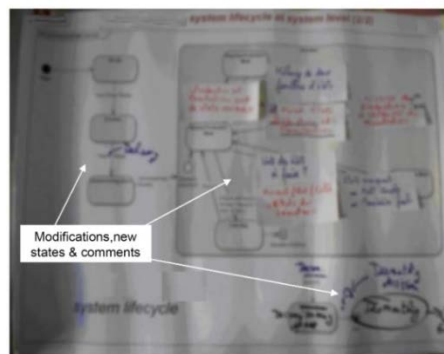


Figure 1.6. Using models to converge on the same vision of a system





Initial life cycle of a system



Shared life cycle of a system

Figure 1.7. Initial and final models as managed during a collaborative systems architecture workshop

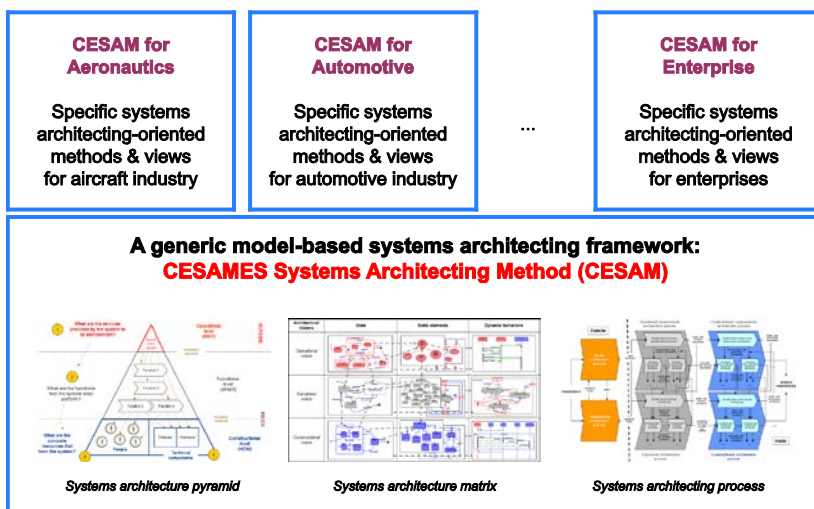
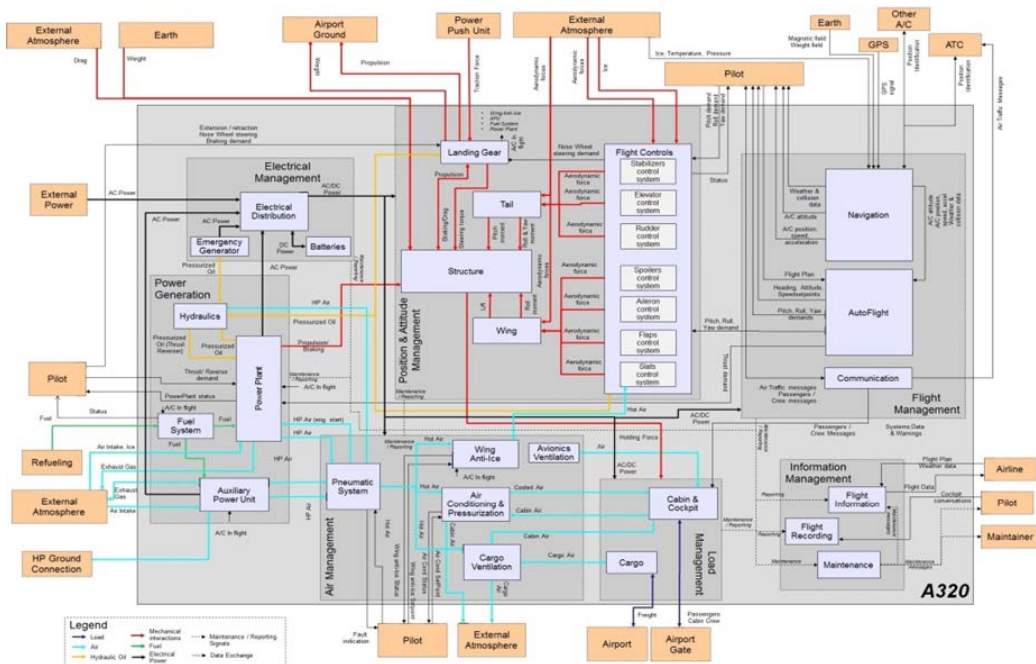
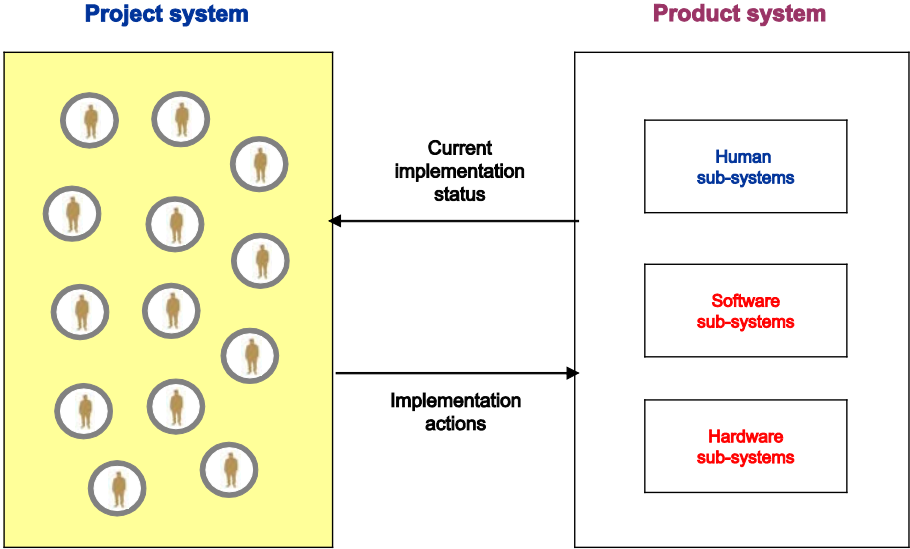


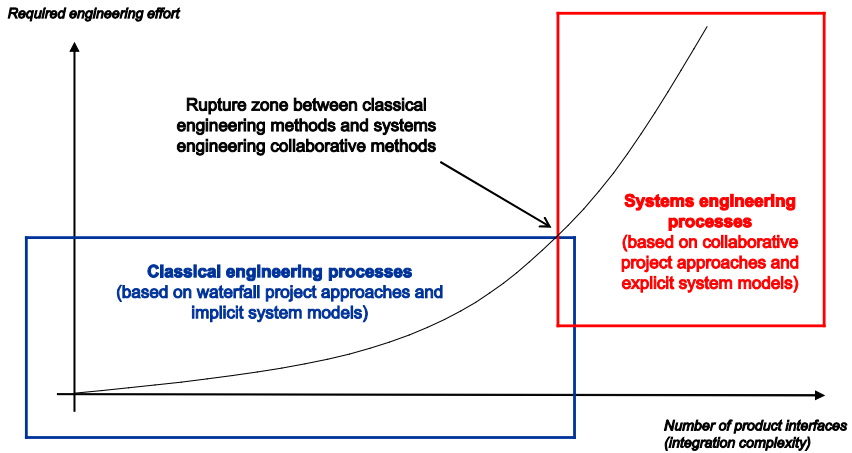
Figure 1.8. Tentative structure of the CESAM frameworks



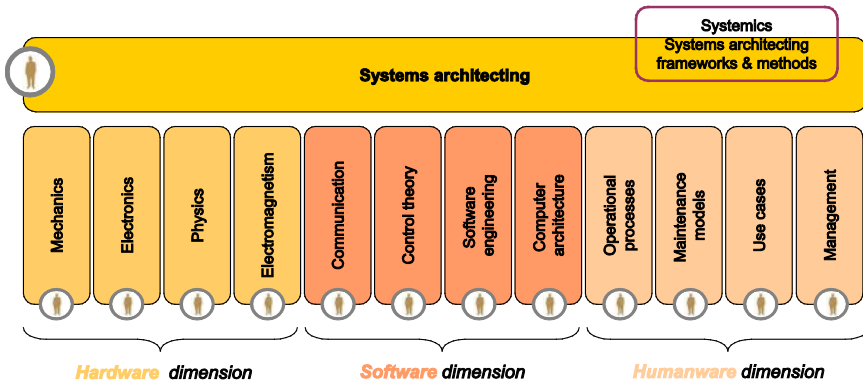
**Figure 1.9.** Example of a standard functional/constructional architecture for an aircraft



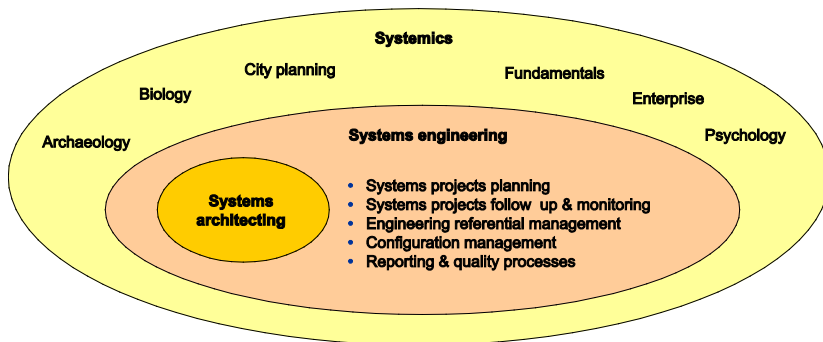
**Figure 2.1.** Product versus project systems



**Figure 2.2.** Project effort and integration complexity relationship



**Figure 2.3.** The integrative and collaborative dimension of systems architecting



**Figure 2.4.** Relative position of systems engineering and systems architecting within systemics

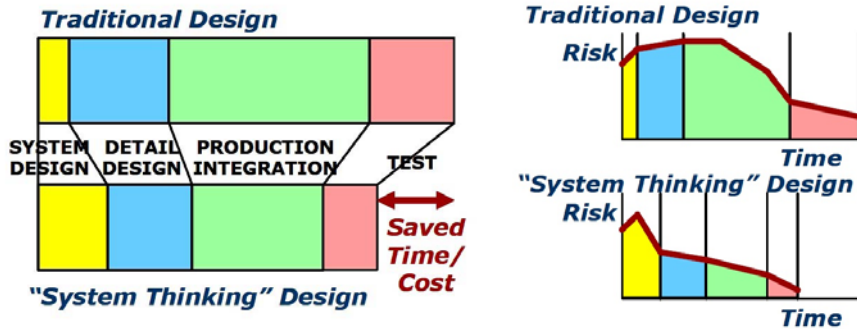


Figure 2.5. Systems architecting as a risk management practice

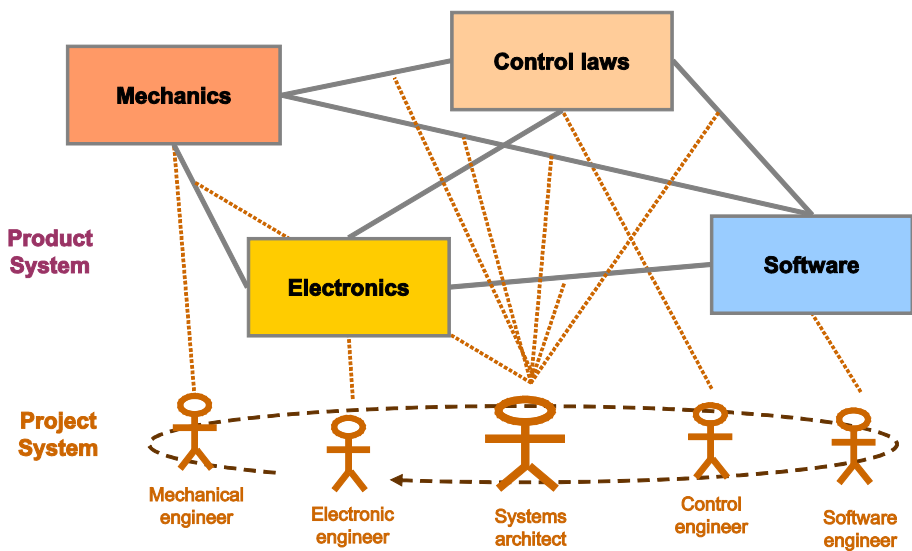


Figure 2.7. The key role of the systems architect

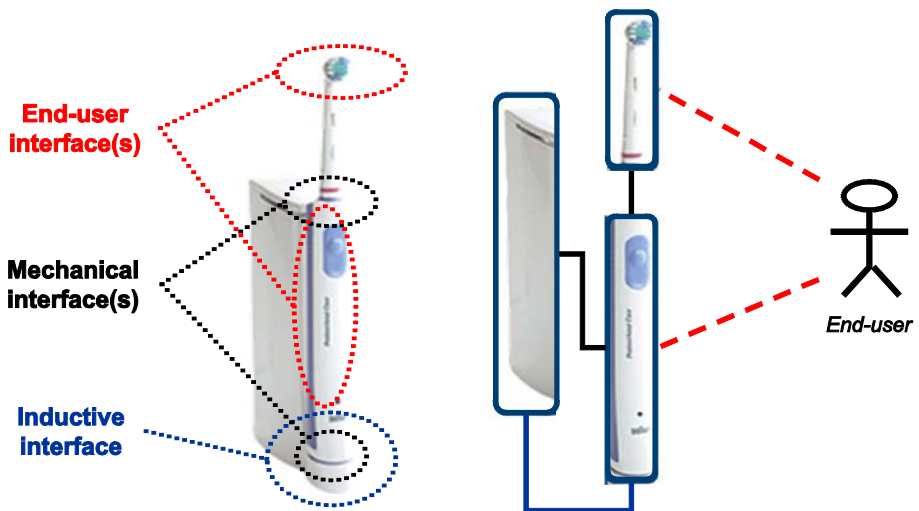


Figure 3.1. Examples of interfaces for an electronic toothbrush

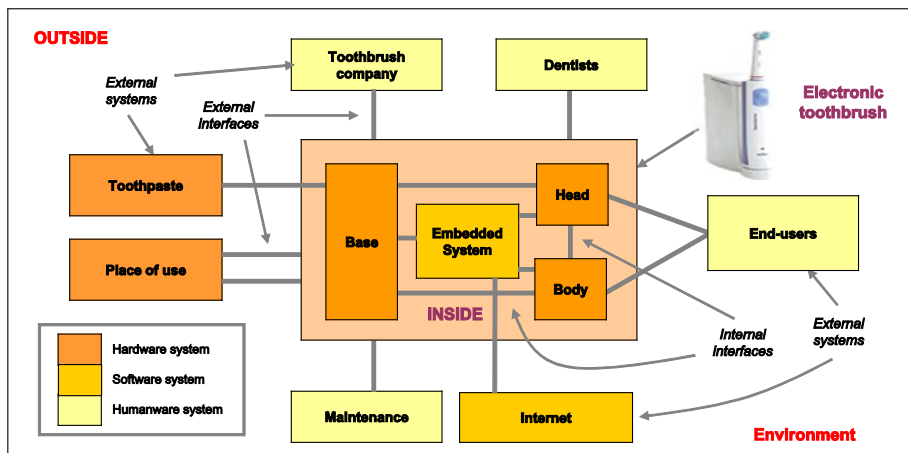


Figure 3.2. Environment of an electronic toothbrush

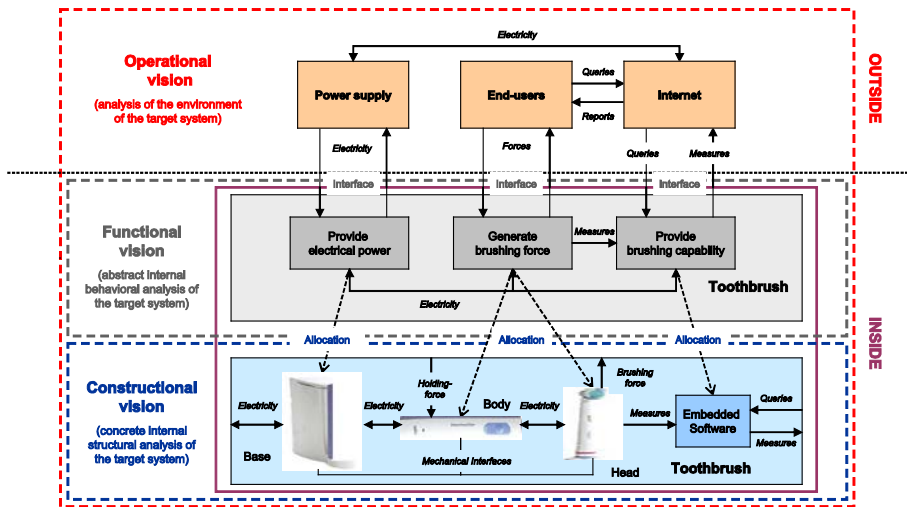


Figure 3.3. Illustration of the three architectural visions on an electronic toothbrush

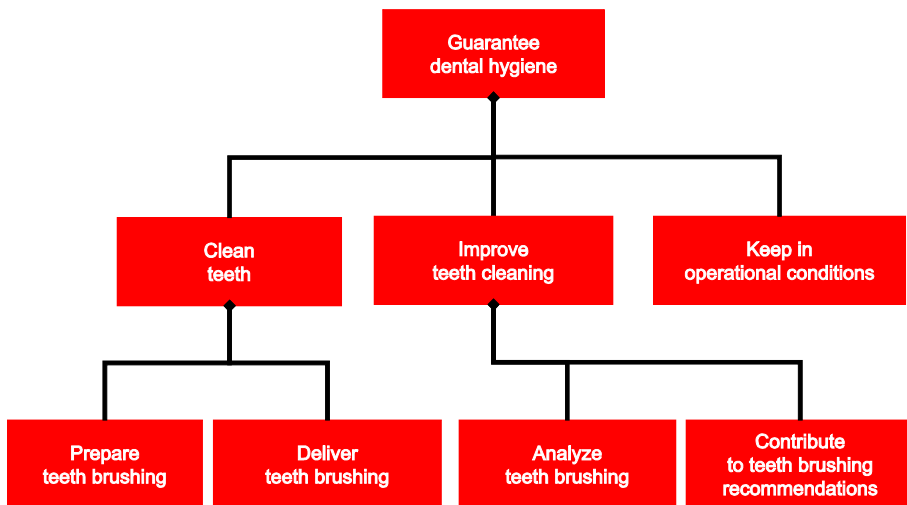
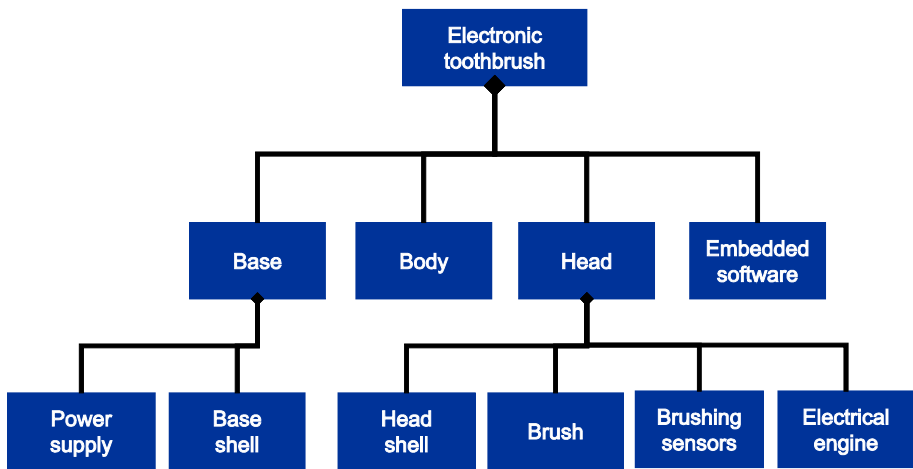
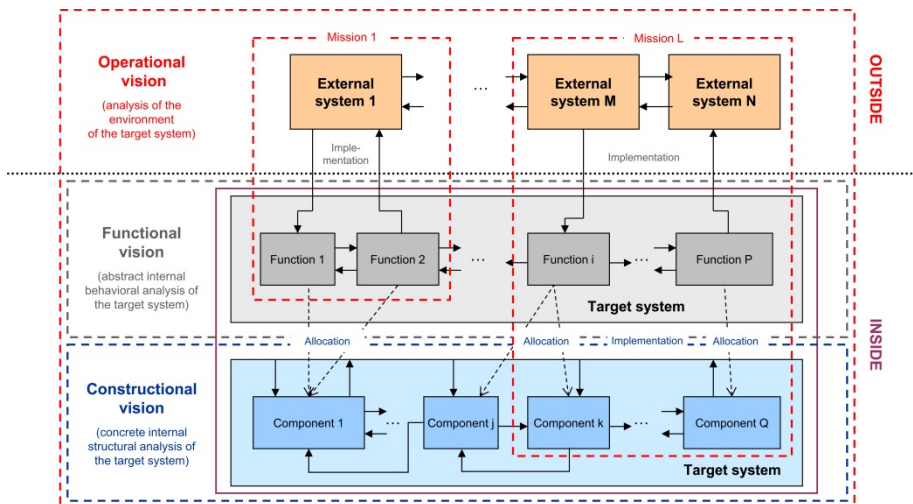


Figure 3.4. Operational vision – mission breakdown structure (MBS) of an electronic toothbrush

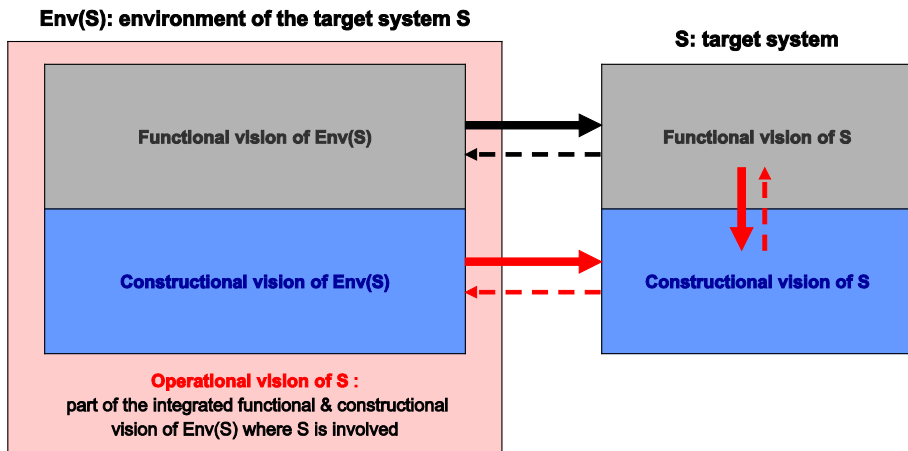


**Figure 3.6.** *Constructional vision – product breakdown structure (PBS) of an electronic toothbrush*

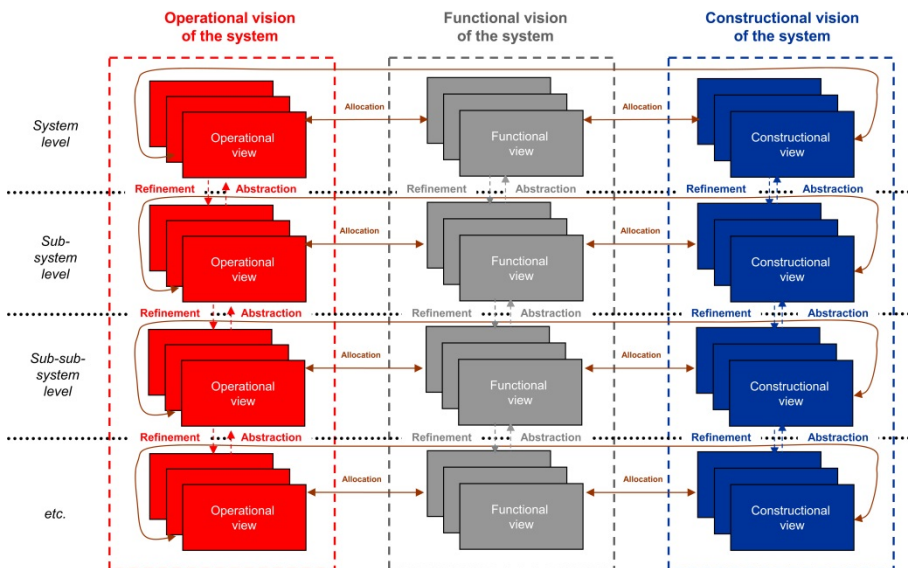


**Figure 3.7.** *Relationships between the three architectural visions*

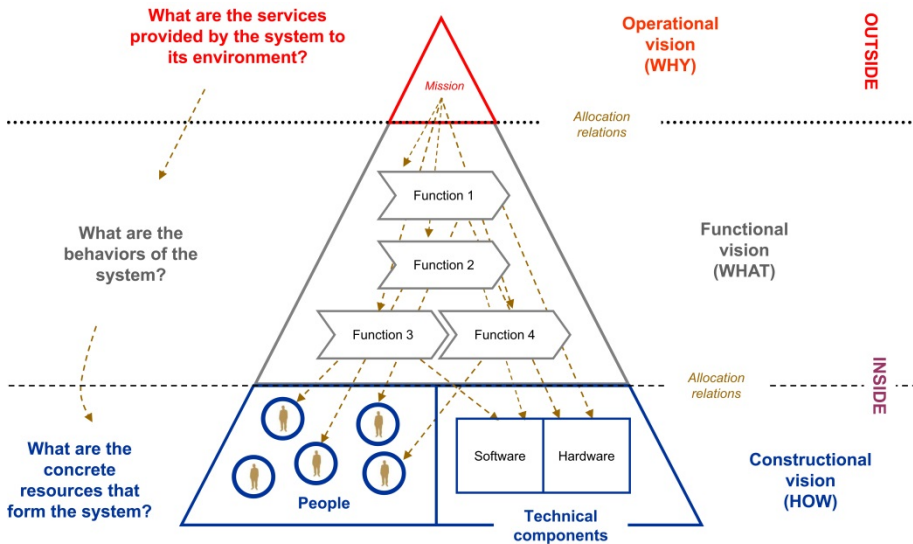




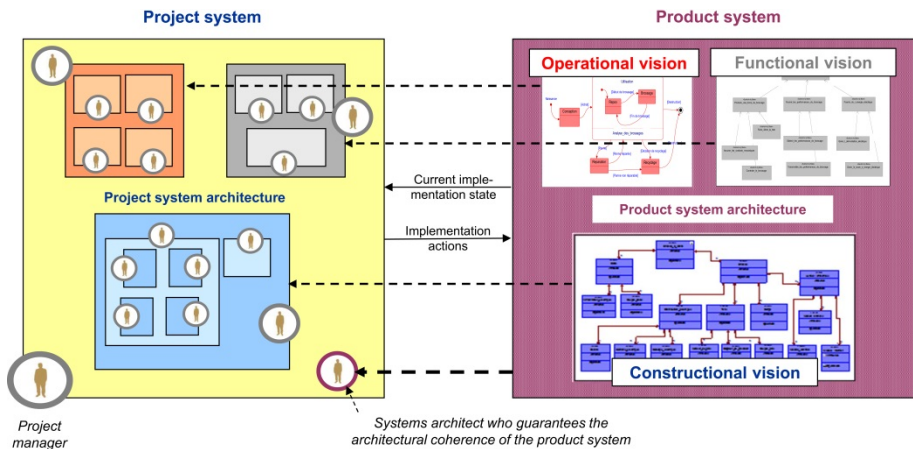
**Figure 3.8.** Relationships existing between the three architectural visions



**Figure 3.9.** Organization of a system model



**Figure 3.10.** *The CESAM systems architecture pyramid*



**Figure 3.11.** *Alignment of the project system architecture with the product system architecture*

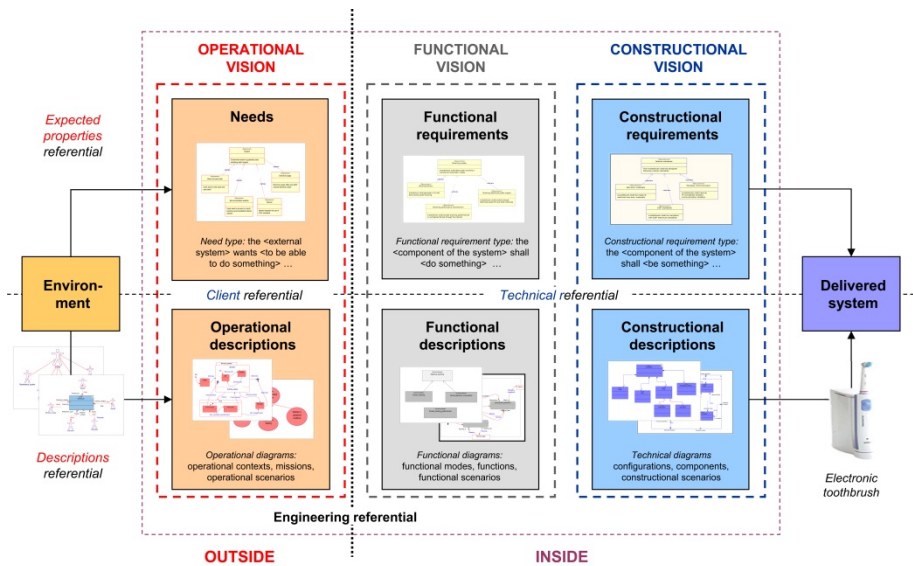


Figure 3.12. Descriptions versus expected properties

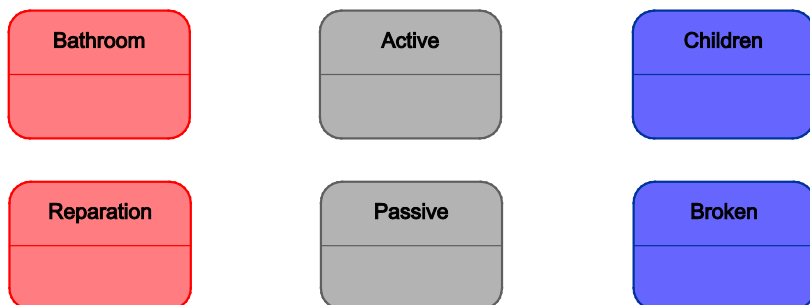


Figure 3.13. Standard representations of states

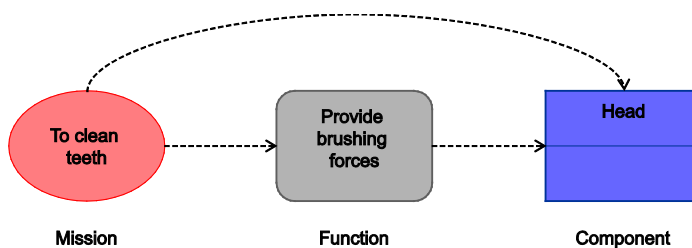
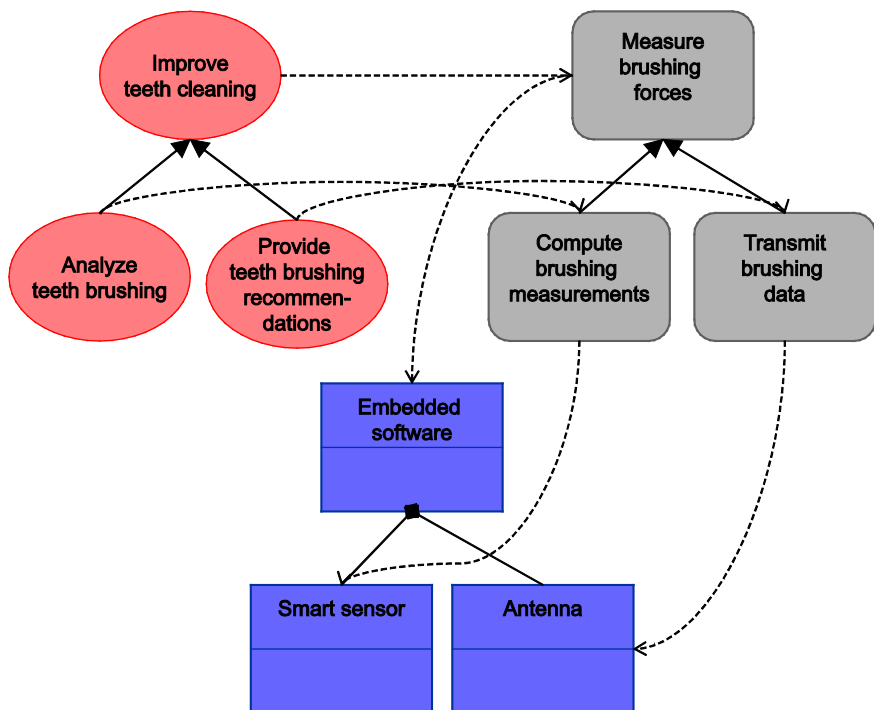
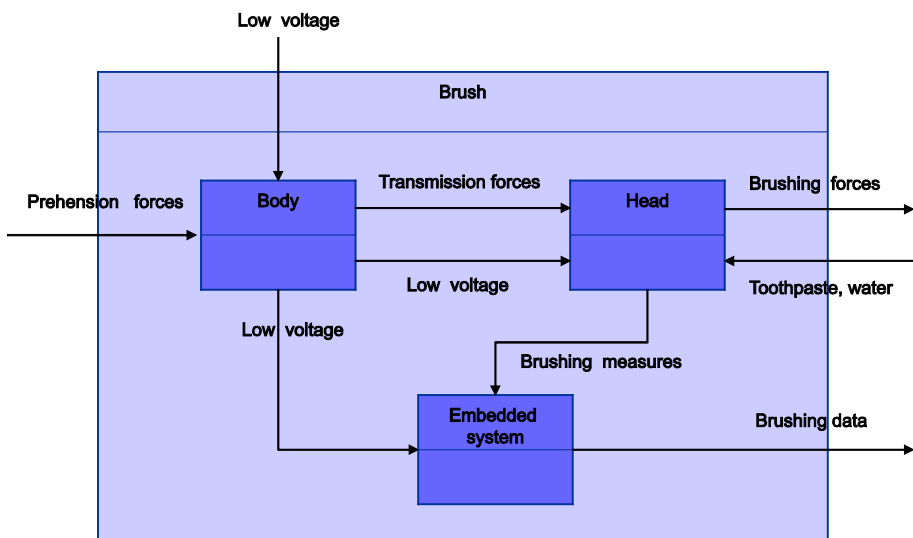


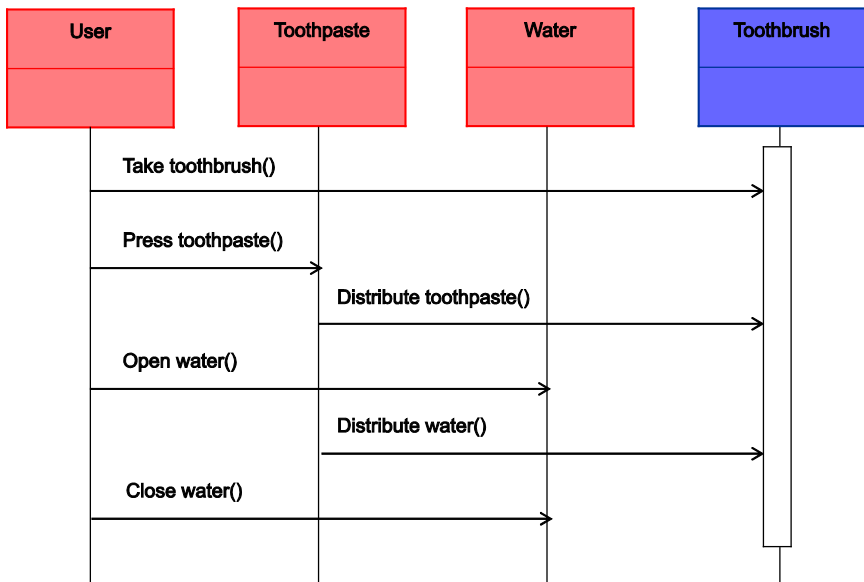
Figure 3.14. Standard representations of static elements



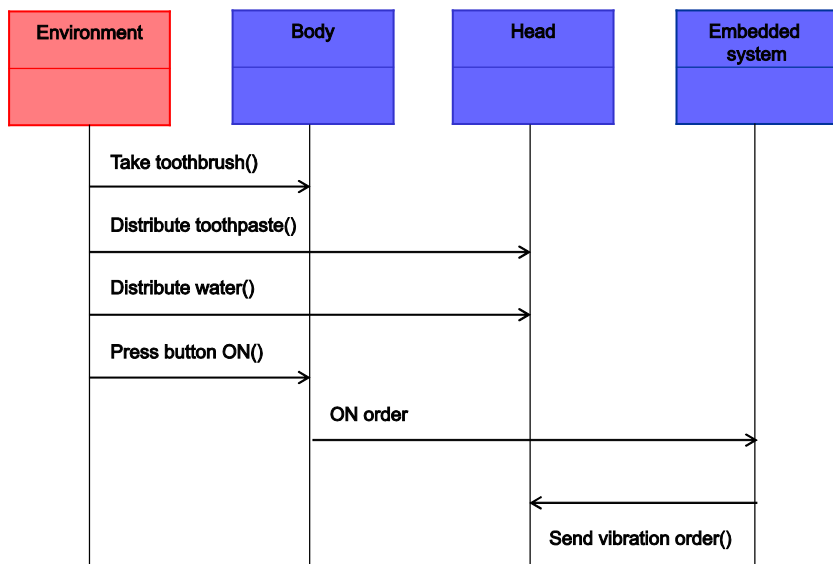
**Figure 3.15.** *Standard representations of integration relations between static elements*



**Figure 3.16.** *Interfaces standard representation*

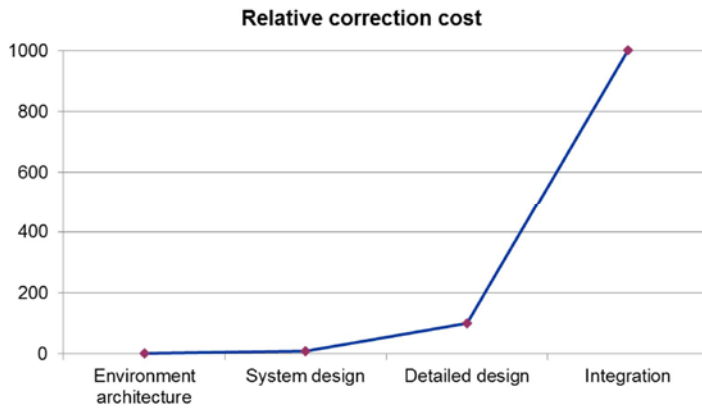


**Figure 3.17.** *Standard representations of an operational dynamic*

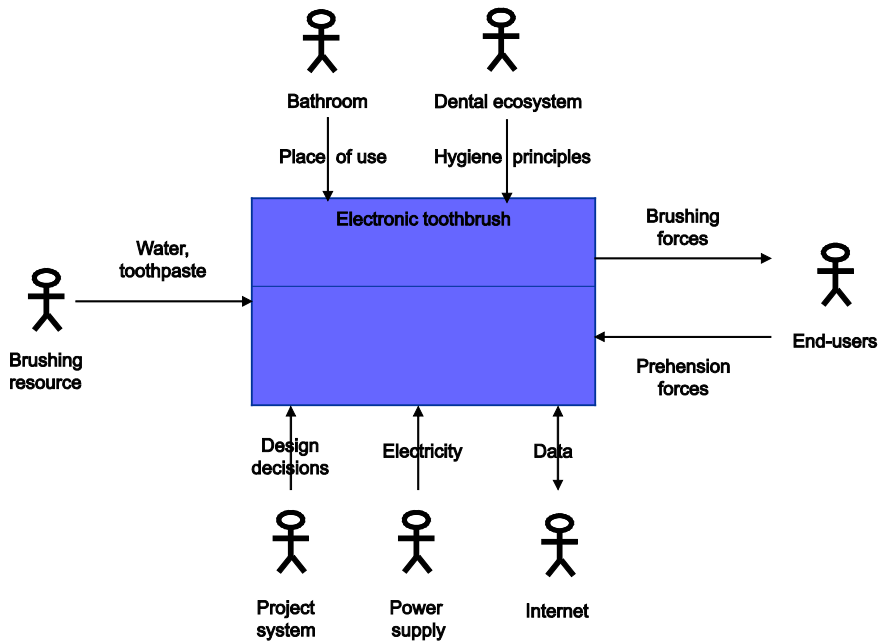


**Figure 3.18.** *Standard representations of a constructional dynamic*



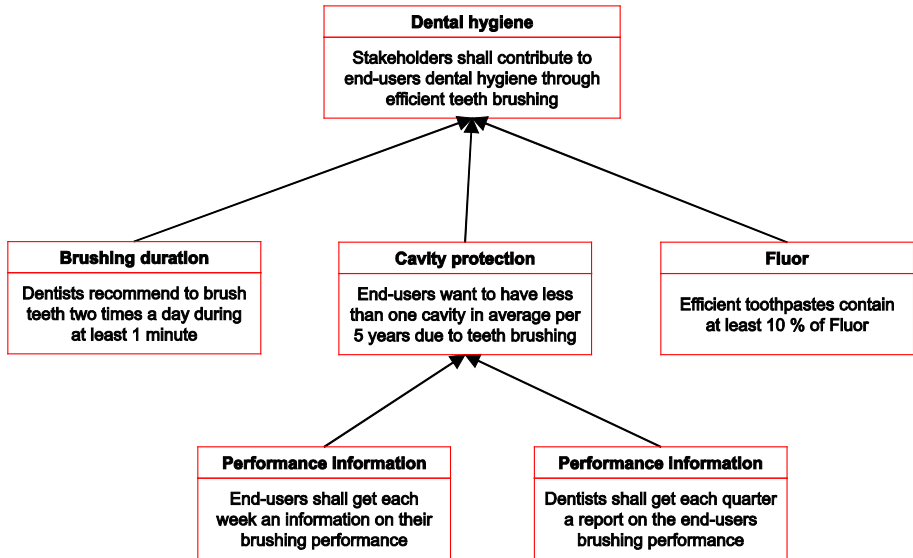


**Figure 4.1.** *Impact of an error in environment architecture*



**Figure 4.3.** *Example of an environment diagram for an electronic toothbrush*

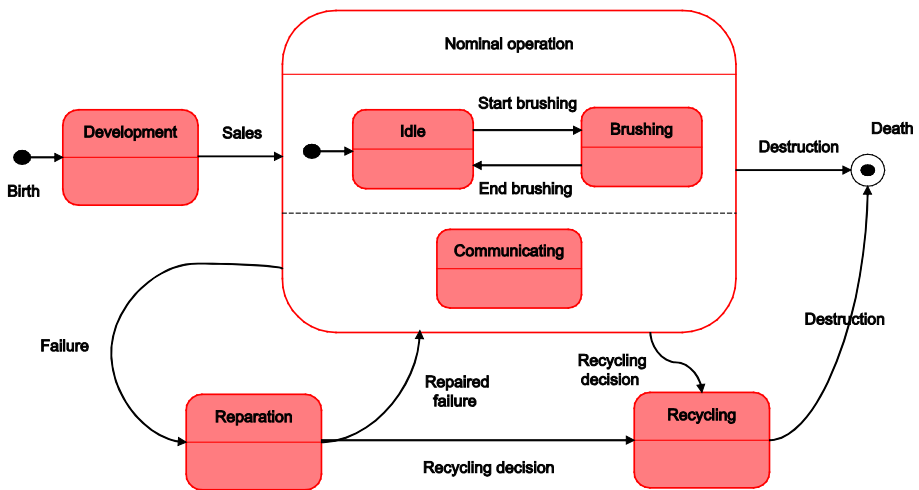




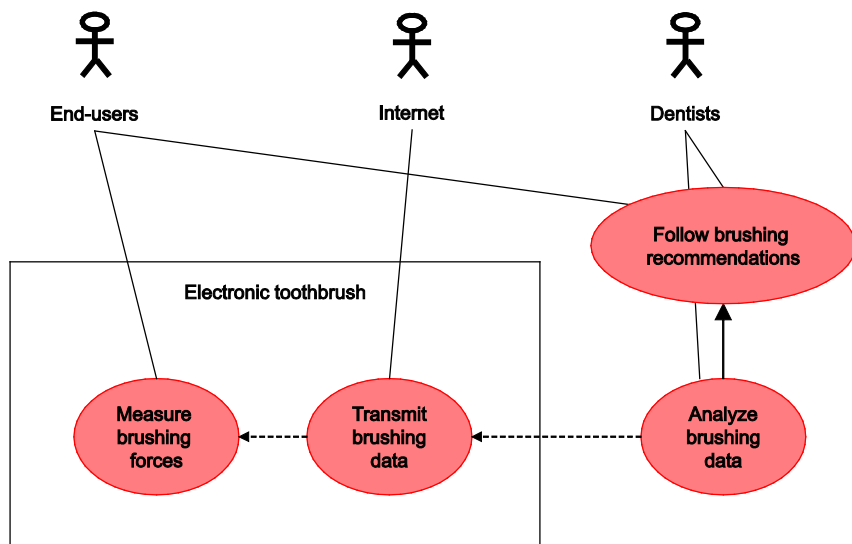
**Figure 5.1.** *Example of a need architecture diagram for an electronic toothbrush*

Temporal relation	Semantics	Graphic representation
Consecutiveness	D is consecutive to C when a termination event of C is exactly equal to an initiation event of D	
Inclusion	D is included in C when the period of time underlying D is contained in the period of time underlying C	
Simultaneity	D is simultaneous to C when the periods of time underlying C and D are exactly equal	

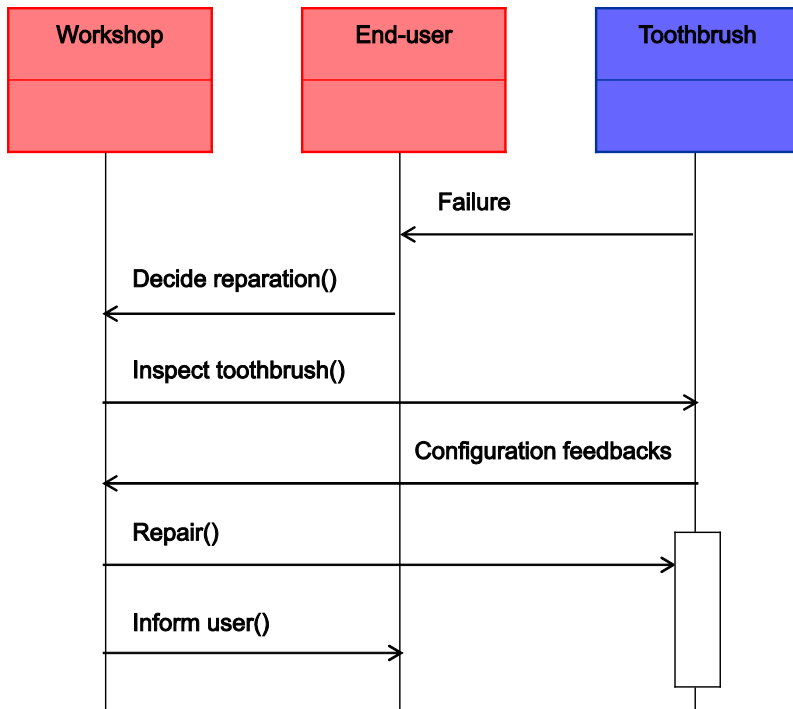
**Table 5.1.** *Graphic representations of temporal relationships between operational contexts*



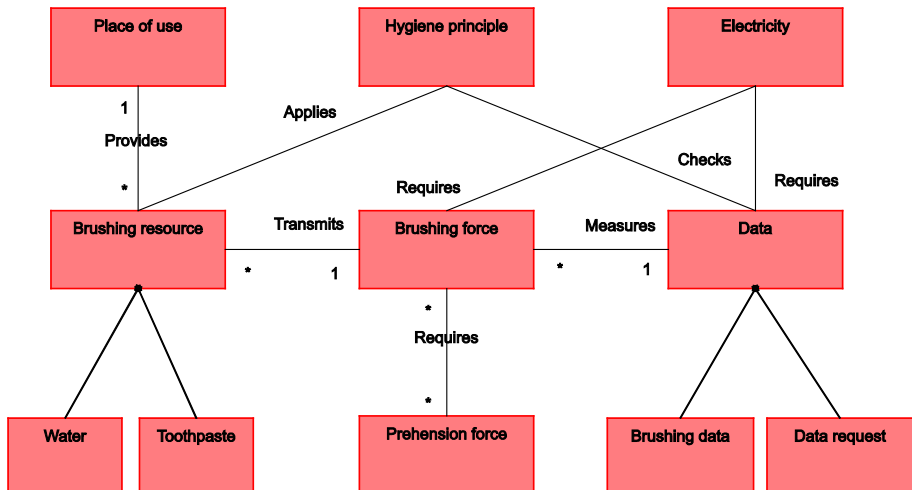
**Figure 5.2.** Example of the lifecycle diagram for an electronic toothbrush



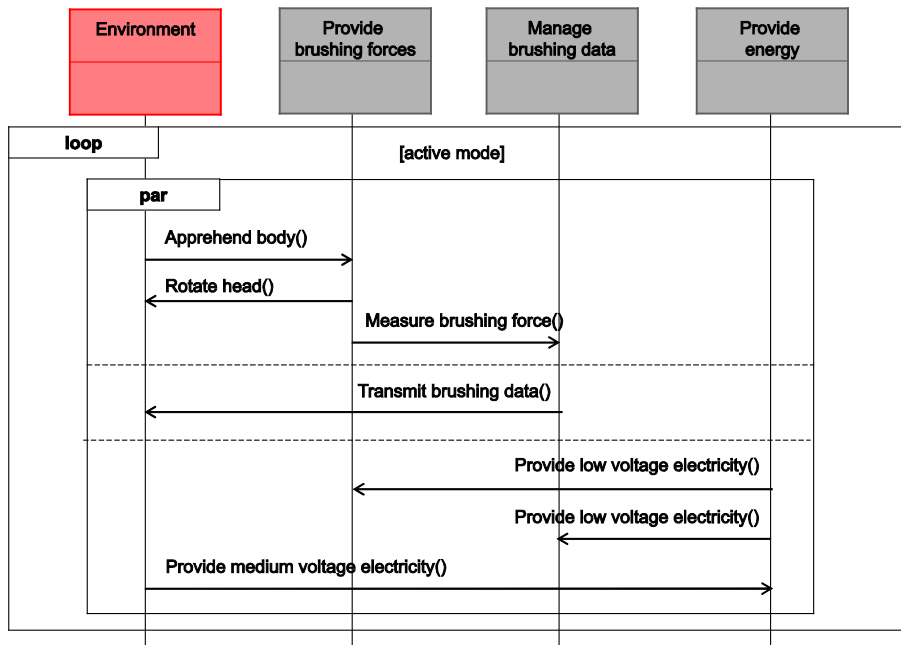
**Figure 5.3.** Example of a use case diagram for an electronic toothbrush



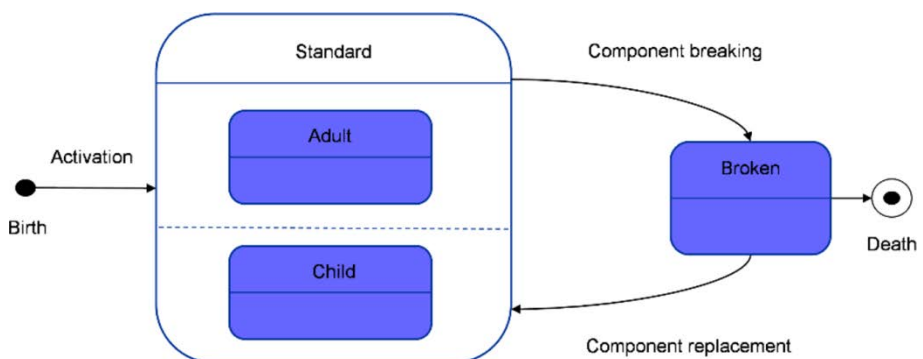
**Figure 5.4.** Example of operational scenario diagram for an electronic toothbrush



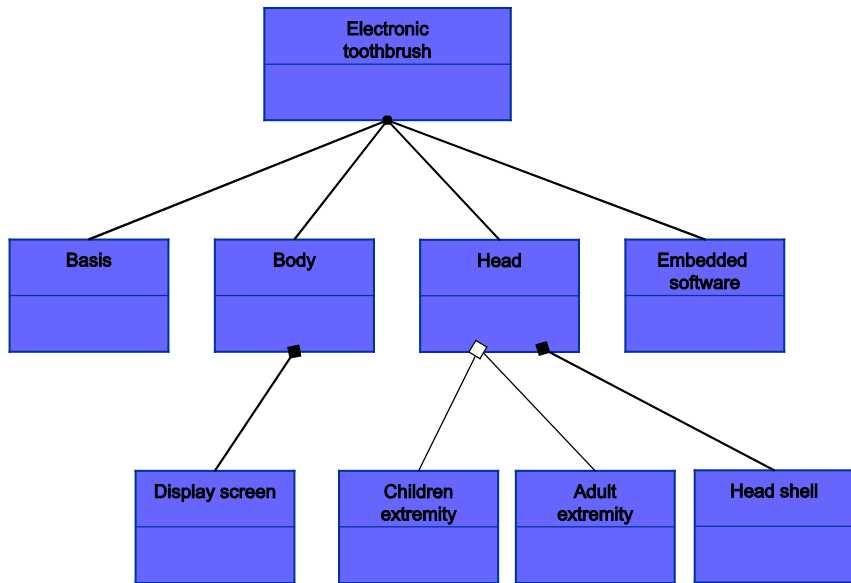
**Figure 5.5.** Example of operational flow diagram for an electronic toothbrush



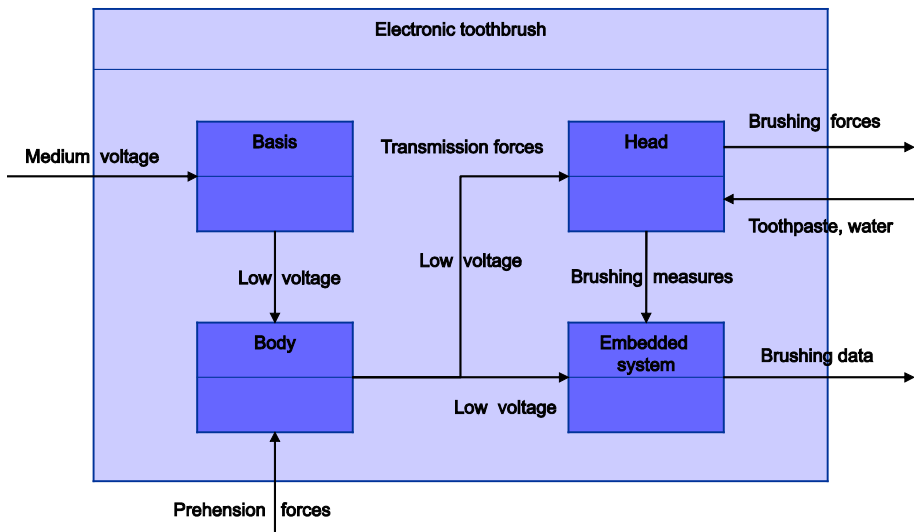
**Figure 6.5.** Example of a functional scenario diagram for an electronic toothbrush



**Figure 7.3.** Example of configuration diagram for an electronic toothbrush



**Figure 7.4.** *Example of a constructional breakdown diagram for an electronic toothbrush*



**Figure 7.5.** *Example of a constructional interaction diagram for an electronic toothbrush*

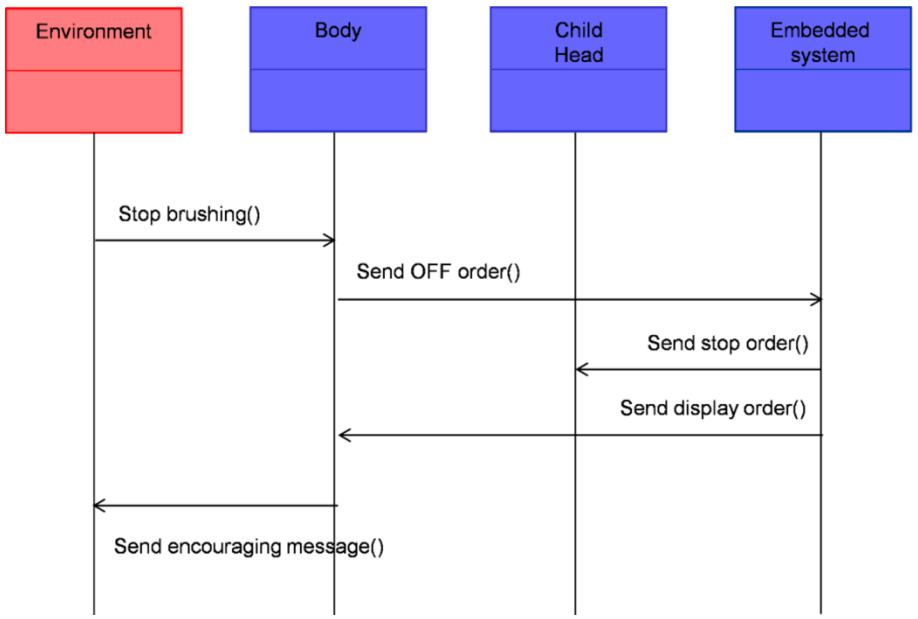


Figure 7.6. Example of a constructional scenario diagram for an electronic toothbrush

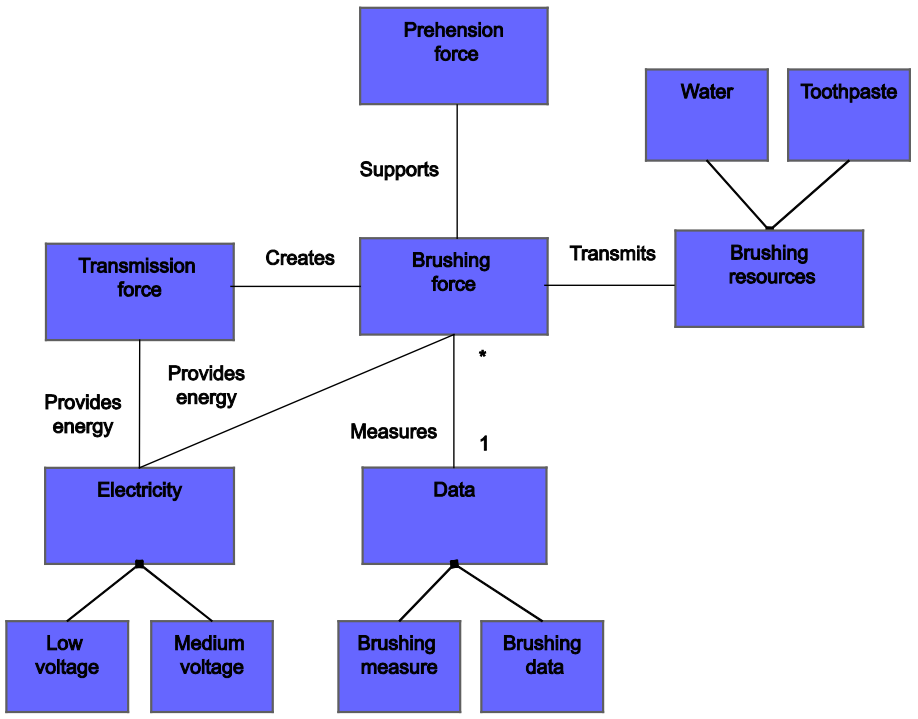


Figure 7.7. Example of a constructional flow diagram for an electronic toothbrush

Initiating event impacting the system S

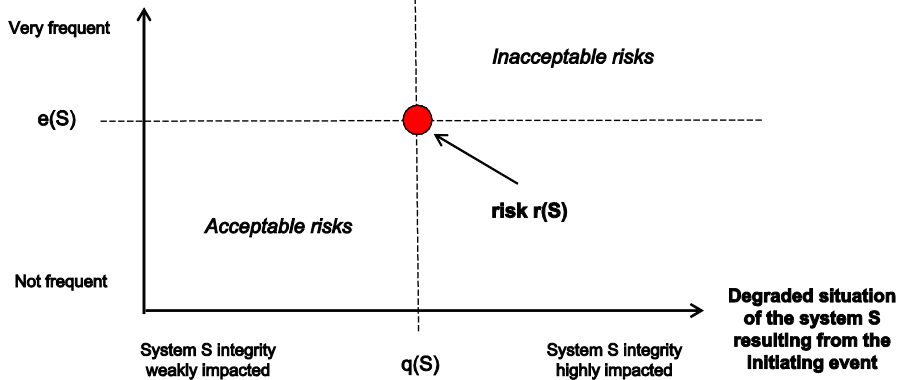


Figure 8.1. The two dimensions of a risk

		Severity of degraded situation resulting from the initiating event			
		Insignificant	Marginal	Critical	Catastrophic
Frequency of the initiating event	Frequent	Undesired	Unacceptable	Unacceptable	Unacceptable
	Probable	Acceptable	Undesired	Unacceptable	Unacceptable
	Occasional	Acceptable	Undesired	Undesired	Unacceptable
	Unlikely	Negligible	Acceptable	Undesired	Undesired
	Improbable	Negligible	Negligible	Acceptable	Acceptable
	Eliminated	Negligible	Negligible	Negligible	Negligible

Figure 8.2. Example of a risk classification grid

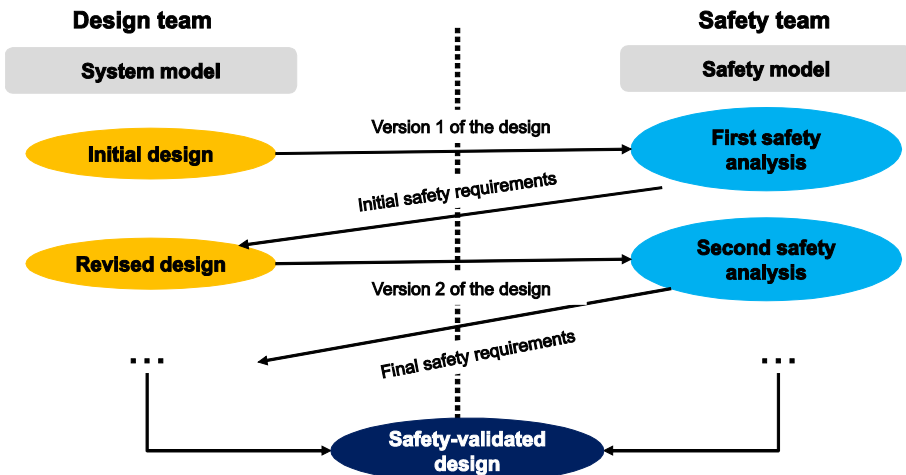
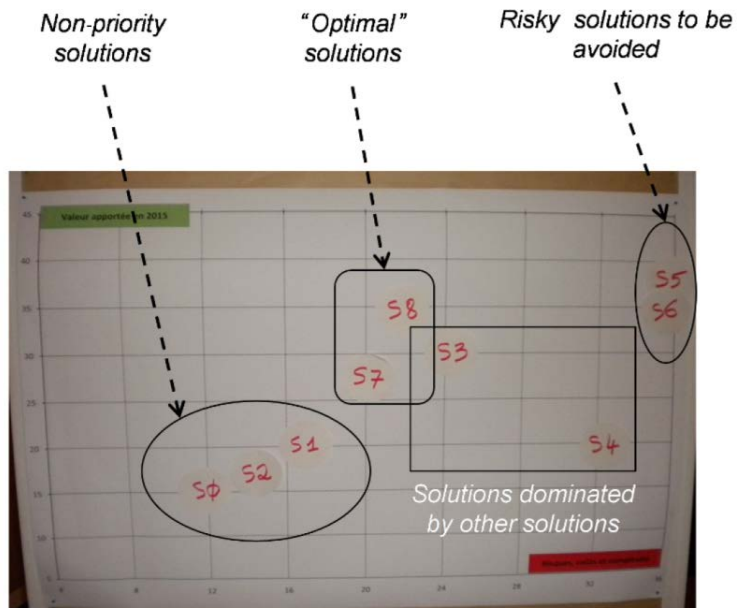


Figure 8.3. Typical interface between design and safety teams according to safety standards



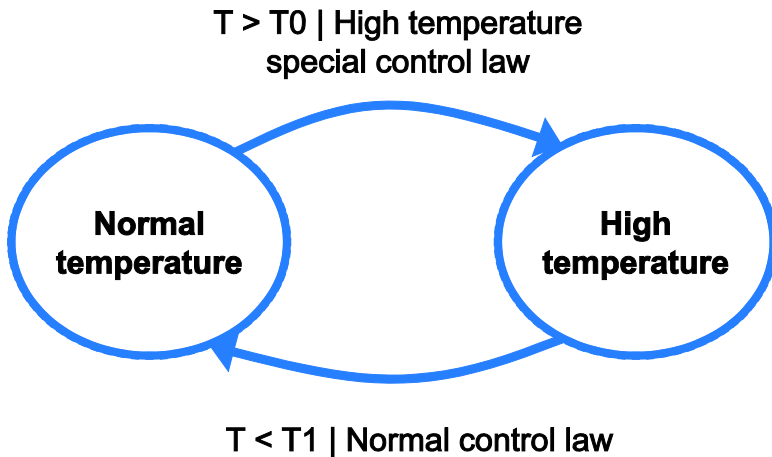


**Figure 9.1.** Example of a collective vote during a prioritization workshop

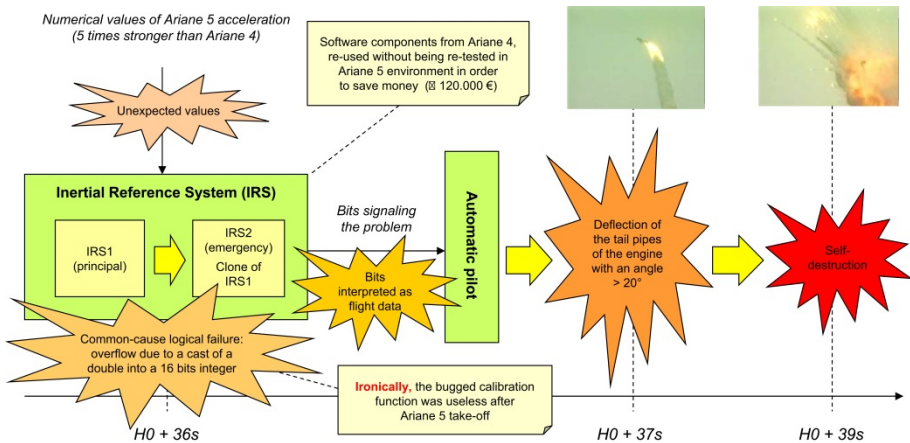


**Figure 9.2.** Example of a collective evaluation during a prioritization workshop





**Figure A2.2.** *The missing operational analysis in the Calcutta subway case*



**Figure A2.3.** *The Ariane 5 case*

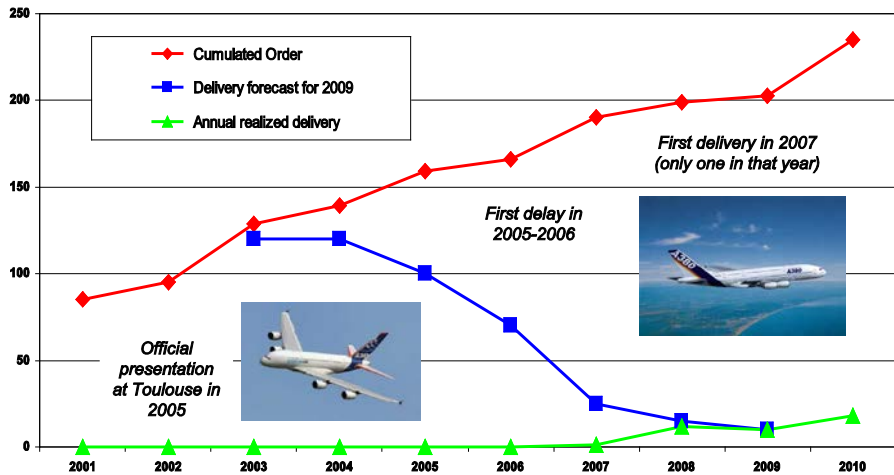


Figure A2.4. The Airbus 380 case

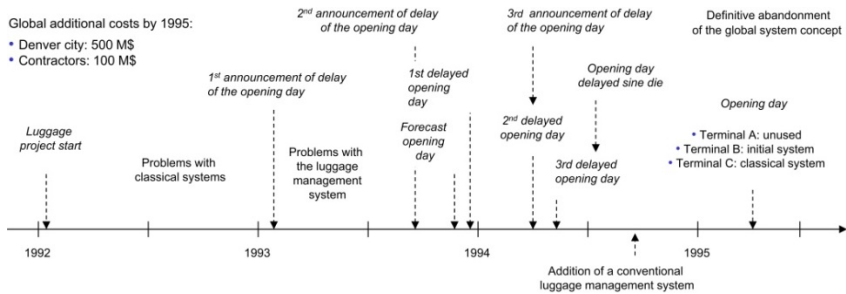
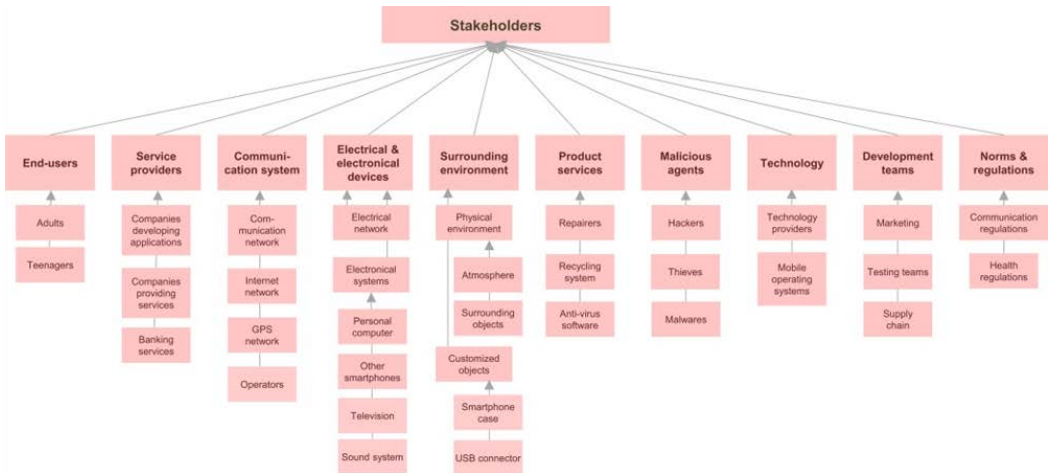


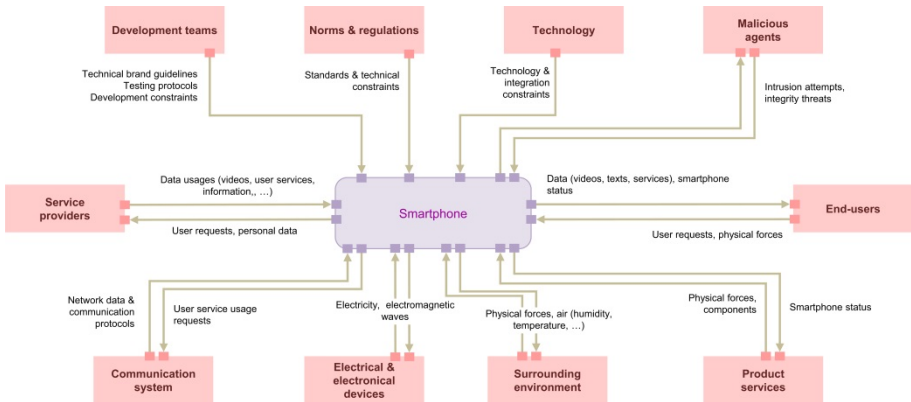
Figure A2.5. The Denver luggage management system case



Figure A3.1. Our system of interest: a smartphone system



**Figure A3.2.** Stakeholder hierarchy diagram of a smartphone system



**Figure A3.3.** Environment diagram of a smartphone system





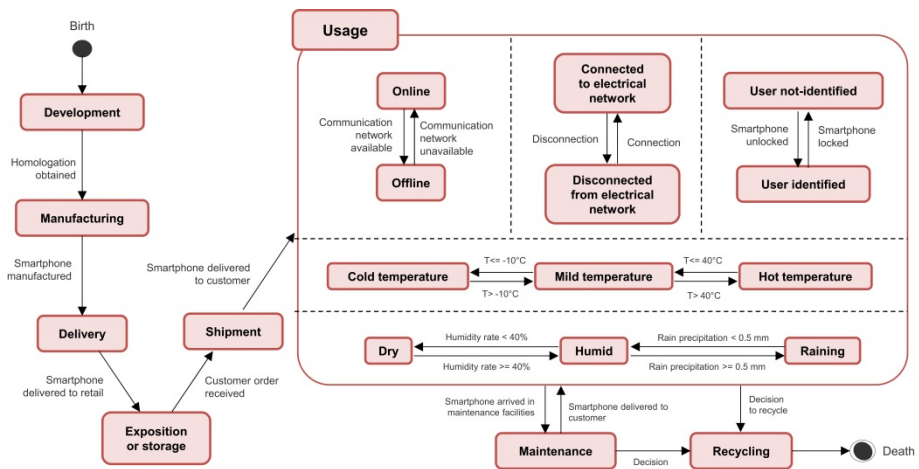


Figure A3.6. Lifecycle diagram of a smartphone system

Lifecycle phase	Use case
Development	Scope smartphone Design smartphone Verify smartphone Validate smartphone Test applications and services Approve smartphone
Manufacturing	Produce smartphone parts Source smartphone parts Assemble smartphone Check smartphone
Delivery	Pack smartphone Transport smartphone Trace smartphone
Exposition or storage	Store smartphone Identify smartphone Make a demo of smartphone Experience smartphone features
Shipment	Ship smartphone to customer Receive smartphone

Lifecycle phase	Use case
Usage	
Connectivity	<b>Offline</b> <ul style="list-style-type: none"> <li>Customise smartphone</li> <li>Know smartphone status</li> <li>Back up smartphone</li> <li>Reset smartphone</li> <li>Get smartphone usage advice</li> <li>Extend smartphone life</li> <li>Use applications and services offline</li> <li>Offer applications and services</li> <li>Connect customised objects</li> <li>Damage smartphone</li> <li>Connect E&amp;E devices</li> </ul> <b>Online</b> <ul style="list-style-type: none"> <li>Troubleshoot smartphone</li> <li>Diagnose smartphone</li> <li>Attack smartphone</li> <li>Ensure confidentiality</li> </ul> <b>Online</b> <ul style="list-style-type: none"> <li>Use applications and services</li> <li>Add new applications and services</li> <li>Update applications and services</li> <li>Send network data</li> <li>Get network data</li> </ul>
Electrical network	<b>Disconnected from electrical network</b> <ul style="list-style-type: none"> <li>Charge smartphone</li> <li>Extend smartphone life</li> </ul> <b>Connected to electrical network</b> <ul style="list-style-type: none"> <li>Charge smartphone</li> <li>Extend smartphone life</li> </ul>
End-user	<b>Absence of end-user</b> <ul style="list-style-type: none"> <li>Unlock smartphone</li> <li>Lock smartphone</li> </ul> <b>End-user usage</b> <ul style="list-style-type: none"> <li>Secure smartphone</li> </ul>
Temperature	<b>Hot temperature</b> <b>Mild temperature</b> <b>Cold temperature</b>

Figure A3.7. List of use cases classified per lifecycle phase of a smartphone system



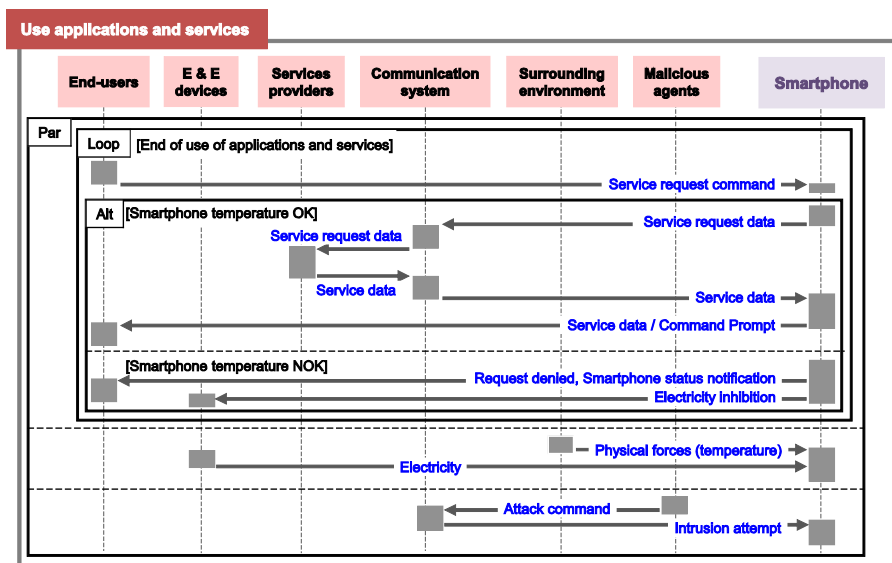


Figure A3.8. Example of an operational scenario diagram of a smartphone system

	Process service				Operate smartphone		Supervise smartphone		Interface with environment		Protect from environment	Manage electrical supply		Communicate				
	Dispatch contents	Centralize input data	Run services	Convert service and device data	Compute operations	Manage memories	Manage operation priorities & modes	Analyse smartphone health	Deliver environment outputs	Acquire environment inputs	Protect from environment	Distribute electricity	Store electricity	Receive electricity	Send data to services	Acquire service data	Send data to devices	Acquire device data
N1									X	X								
N2							X	X	X									
N3																		

N1

Electronic systems shall be able to exchange data with wired, Wi-Fi, NFC and Bluetooth protocols for all electronic systems built after 2019 in connected usage phase.

N2

End-users shall be able to know the smartphone status about energy level, health, data storage and memory use in real time in usage phase

N3

The recycling system shall be able to recycle 95% of the smartphone components at a cost lower than 2 dollars per smartphone.

Figure A3.10. Partial need to the functional requirement matrix of a smartphone system

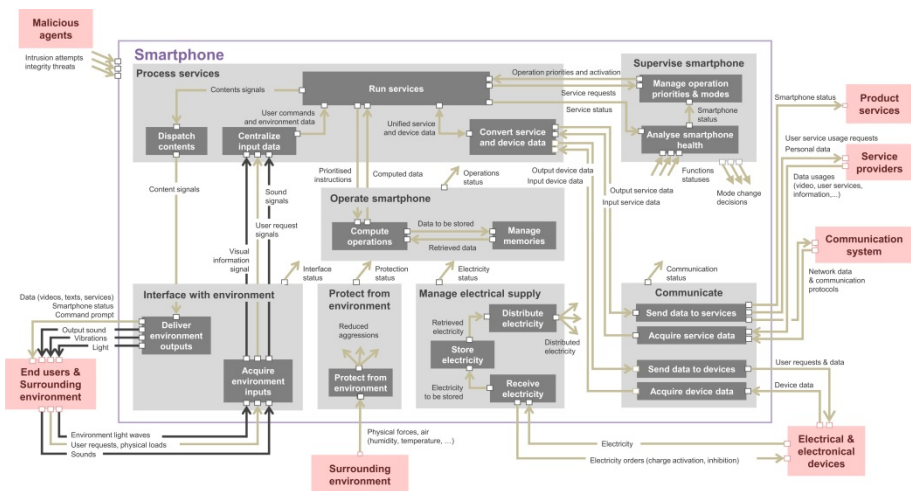


Figure A3.12. Functional interaction diagram of a smartphone system

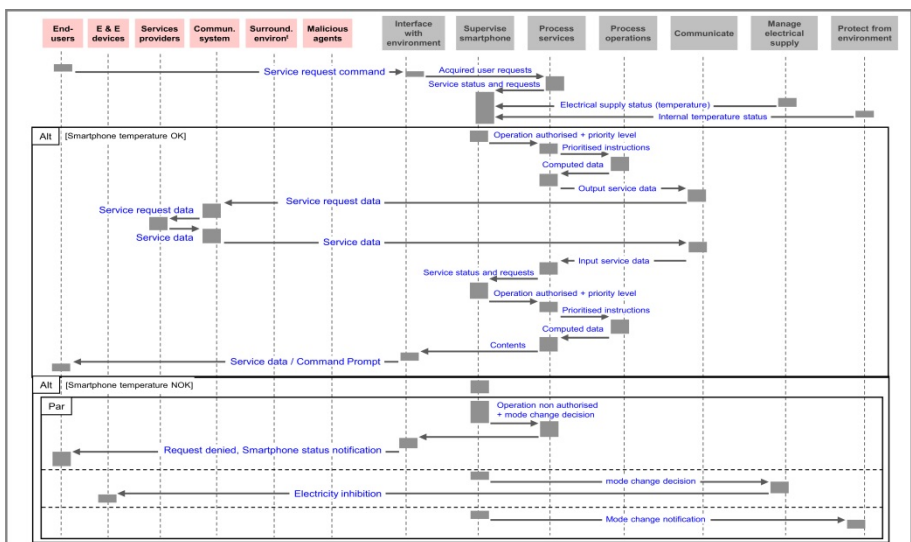
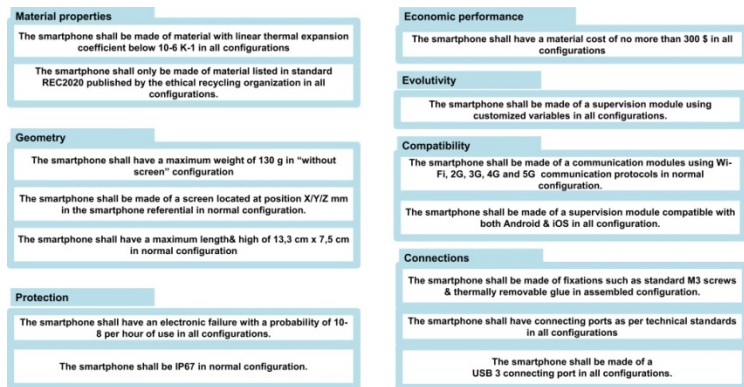


Figure A3.13. Example of a functional scenario diagram of a smartphone system



**Figure A3.14.** Constructional requirement architecture diagram of a smartphone system

	Motherboard						Software package					Mechanical Assembly			Power unit			Communication module		Audio & video assembly							
	Ports	Flash memory	CPU	Storage Unit	RAID Card	Main board	Operating system	BIOS	Firmware software	Power Management software	Service providers Application	Buttons	Casing	Display device	Battery	Charging interface	Electrical converter	Electrical distribution	Antennas	Cards	Connectings	Speakers	Microphone	Flash light	Camera lense	Light sensor	Vibrating device
N1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
N2																											
F1									x												x						
...																											

N1

End-users shall be able to spend maximum one third of an average monthly salary in their country when buying the smartphone

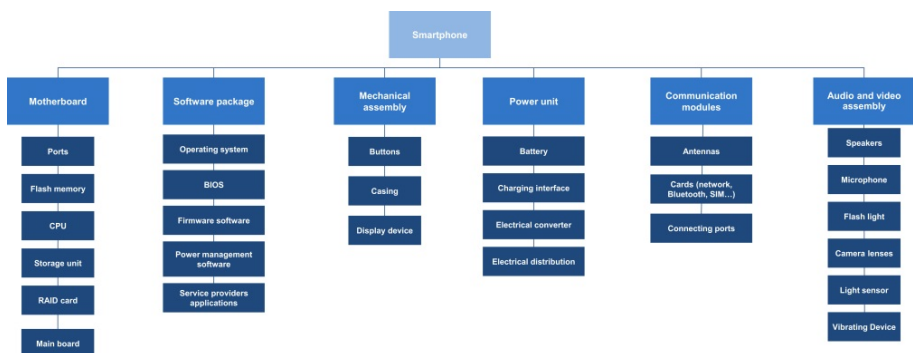
N2

Customized objects shall be able to be interfaced with smartphone without no impact on their current design in all phases.

F1

The smartphone shall supervise smartphone with a possibility to customize the supervision policy

**Figure A3.15.** Partial need and functional requirement to the constructional requirement matrix of a smartphone system



**Figure A3.16.** Product breakdown structure of a smartphone system

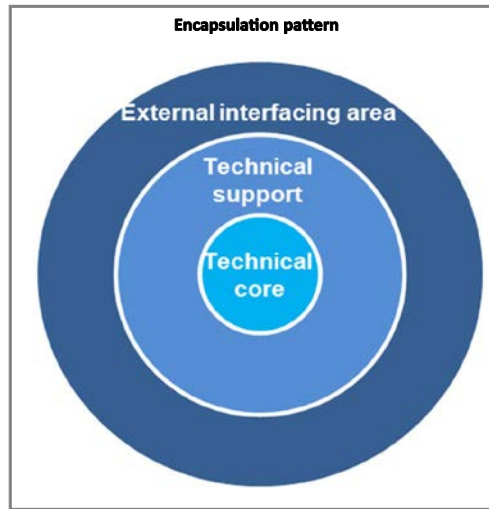


Figure A3.17. Encapsulation pattern

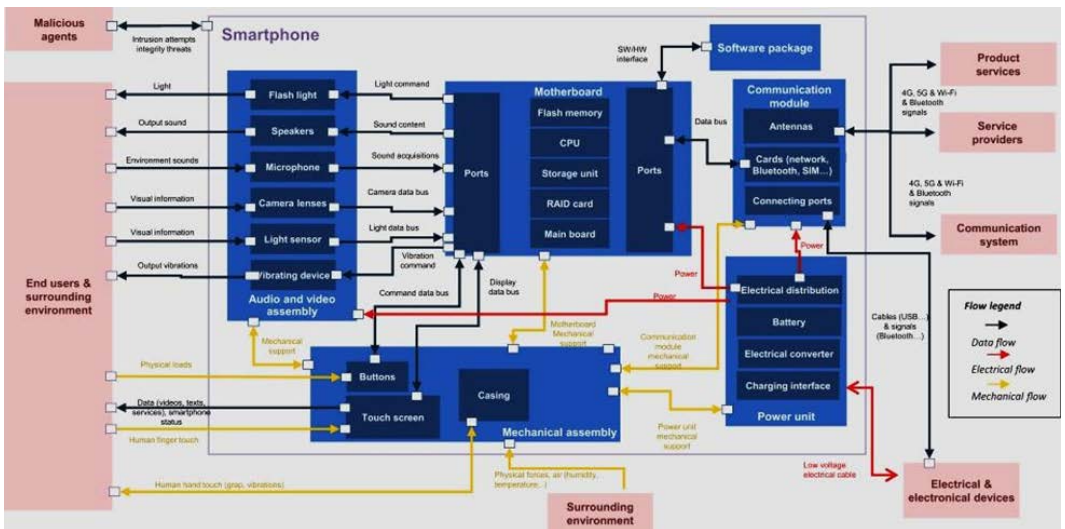
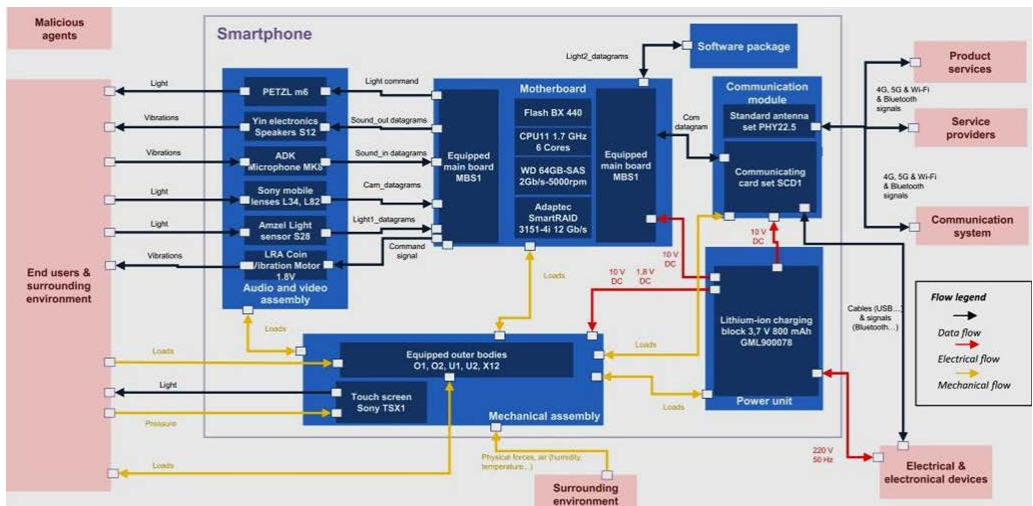


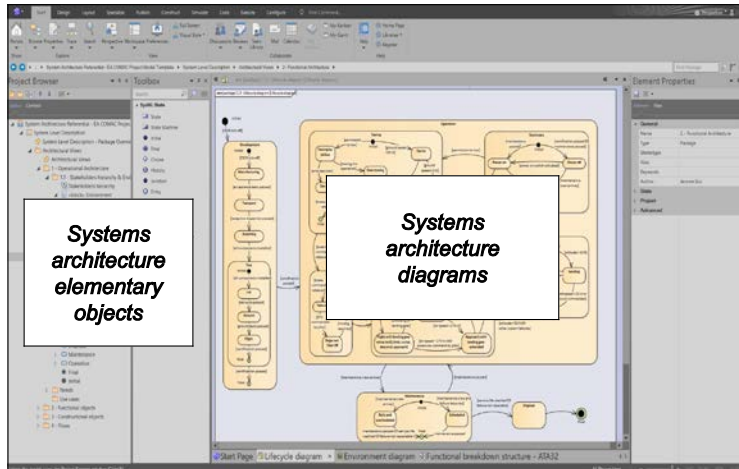
Figure A3.18. Constructional interaction diagram of a smartphone system

Component	Building block	Make or buy policy	Component	Building block	Make or buy policy
<b>Main board &amp; Ports</b>	Equipped main board MBS1	Make	<b>Battery</b>	Lithium-ion charging block 3.7 V 800 mAh GML900078	Buy
<b>Flash memory</b>	Flash BX 440	Buy	<b>Charging interface</b>		
<b>CPU</b>	CPU11 1.7 GHz 6 Cores	Make	<b>Electrical converter</b>		
<b>Storage unit</b>	WD 64GB-SAS 2Gb/s-5000rpm	Buy	<b>Electrical distribution</b>		
<b>RAID Card</b>	Adaptec SmartRAID 3151-4i 12 Gb/s	Buy	<b>Antennas</b>	Standard antenna set PHY22.5	Buy
<b>Operating system</b>	OS S1	Develop	<b>Cards</b>	Communicating card set SCD1	Buy
<b>BIOS</b>	BIOS S1	Develop	<b>Connecting ports</b>		
<b>Firmware software</b>	Firmware software S1	Develop	<b>Speakers</b>	Yin electronics Speakers S12	Buy
<b>Power mgt software</b>	Power mgt software modules PMSS1	Develop	<b>Microphone</b>	ADK Microphone MK8	Buy
<b>Service providers application</b>	software modules M1, M2, M3, M4	Develop	<b>Flash light</b>	PETZL m6	Buy
<b>Buttons</b>	Equipped outer bodies O1, O2, U1, U2, X12	Make	<b>Camera lenses</b>	Sony mobile lenses L34, L82	Buy
<b>Casing</b>			<b>Light sensor</b>	Amzel Light sensor S28	Buy
<b>Display device</b>	Touch screen Sony TSX1	Buy	<b>Vibrating Device</b>	LRA Coin Vibration Motor 1.8V	Buy

**Figure A3.19.** *Implementing a constructional architecture of a smartphone system*



**Figure A3.20.** *Implementation architecture of a smartphone system*



**Figure A4.1.** *Example of a system modeling tool interface*