Development methods

Lecture 2

Schedule

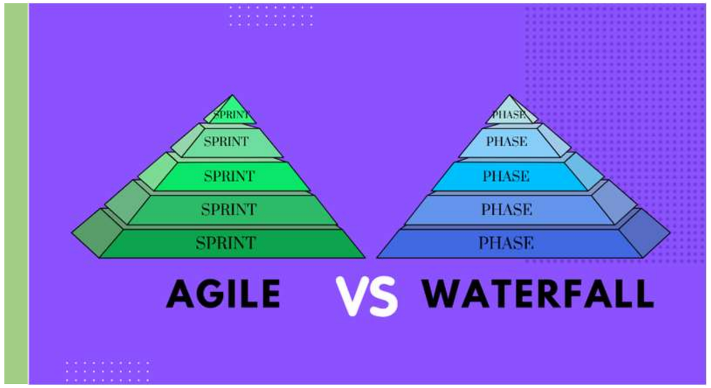
Week nr.	Date	Lecture (Wednesday)			Lab (Wednesday)		Comment
1	09.04.	1	General information		1	Lab	
2	09.11.	2	Development methods		2	Lab	Online
3	09.18.	3	Design goals and requirements		3	Lab	
4	09.25.	4	Conceptualization I		4	Lab	
5	10.02.	5	Design guidelines		5	Lab	
6	10.09.	6	Testing strategies in the automotive industry		6	Lab	
7	10.16.	T1	Midterm exam I.				
8	10.23.	B	National holiday				
9	10.30.	7	System level testing		T1 R	Exam 1 - Retake	Online
10	11.06.	8	Performance and reliability testing		7	Lab	
11	11.13.	9	Troubleshooting and error calculation		8	Lab	
12	11.20.	10	Project management		9	Lab	Online
13	11.27.	T2	Midterm exam II.				
14	12.04.	T2R	Exam 2 - Retake				

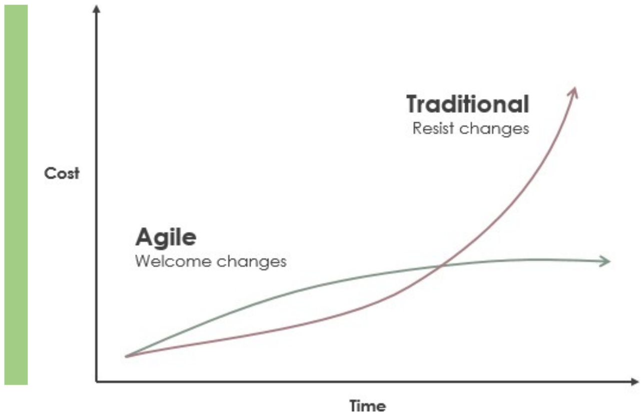
Overview of development methodologies in engineering

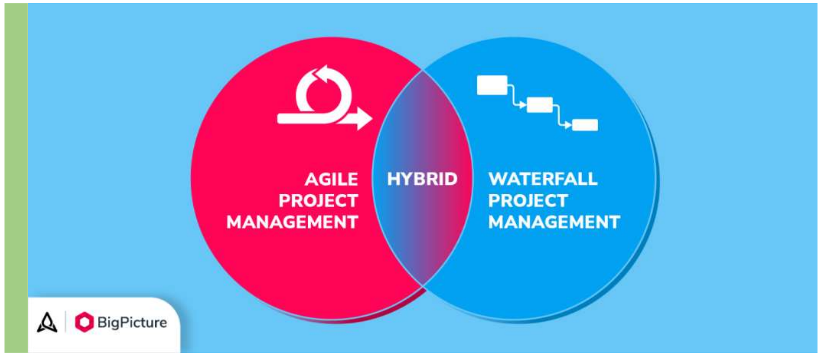
- **Definition:** Development methodologies are structured approaches used to plan, design, develop, test, and deliver engineering projects. They provide a systematic framework that ensures consistency, efficiency, and quality throughout the project lifecycle.

- **Types:** There are various methodologies employed in engineering, including Waterfall, Agile, V-Model, Spiral, and Iterative processes. Each has its own set of principles, processes, and best practices tailored to different project requirements and constraints.

Overview of development methodologies in engineering







https://www.visual-paradigm.com/scrum/classical-vs-agile-project-management/ ; https://bpktech.com/bpktech/agile-vs-waterfall-methodology/; https://www.linkedin.com/pulse/adopting-hybrid-agile-project-management-methodology-factors-dhaon-vwqoc/

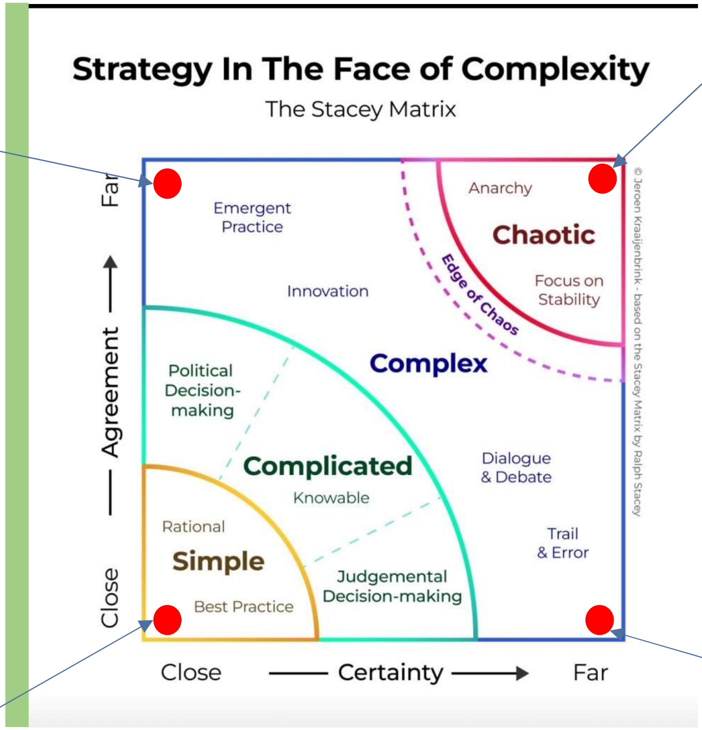
Overview of development methodologies in engineering – Stacey Matrix

Complex

The technological means are understood, but the market requirements and user preferences are uncertain.

Chaotic

Both the requirements (what needs to be done) and the means (how to do it) are uncertain and changing rapidly.



Simple

The requirements are clear, and the technology/processes to achieve them are well-understood.

Complex

The requirements are well-understood, but the technical means to achieve them might be complex and require expert knowledge.

https://myjmr.org/2023/10/20/the-stacey-matrix/ ;

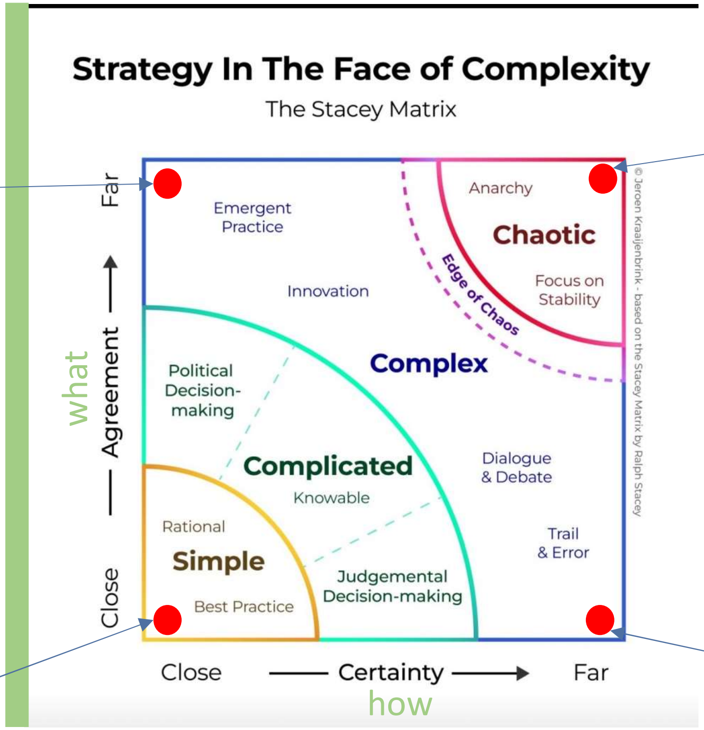
Overview of development methodologies in engineering – Stacey Matrix

BME Automotive Technologies

Complex

The technological means are understood, but the market requirements and user preferences are uncertain.

Innovating a new product based on existing technology, like a new model of a smartphone with advanced features.



Chaotic

Both the requirements (what needs to be done) and the means (how to do it) are uncertain and changing rapidly.

A major automotive company discovers a critical defect in one of their popular car models that poses a severe safety risk, such as faulty airbags or braking systems. This discovery requires an immediate and extensive vehicle recall affecting millions of cars worldwide.

Simple

The requirements are clear, and the technology/processes to achieve them are well-understood.

Producing a well-defined product, such as a standard model of a car that the company has been manufacturing for years.

Complex

The requirements are well-understood, but the technical means to achieve them might be complex and require expert knowledge.

Developing custom software for a client in a familiar industry, like a financial institution.

https://myjmr.org/2023/10/20/the-stacey-matrix/ ;

Overview of development methodologies in engineering

- **Consistency and Quality:** A systematic approach helps maintain consistency in design and development processes, which is crucial for ensuring high-quality outcomes. This is especially important in the automotive industry, where precision and reliability are paramount.

- **Efficiency:** Methodologies streamline the development process, making it more efficient. They provide clear guidelines and workflows that reduce redundancy and optimize resource utilization.

- **Risk Management:** Systematic approaches include risk assessment and mitigation strategies, helping to identify potential issues early in the development process and implement corrective actions before they escalate.

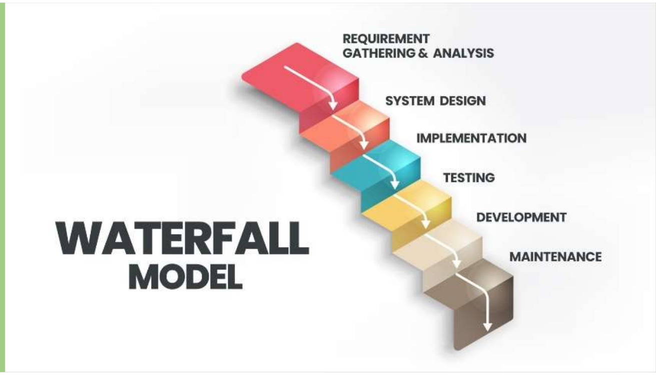
- **Collaboration:** These methodologies facilitate better collaboration among cross-functional teams, ensuring that all stakeholders are aligned with project goals and timelines.

- **Documentation and Traceability:** Well-defined methodologies ensure thorough documentation and traceability of design and development activities. This is vital for regulatory compliance, troubleshooting, and future enhancements.

Waterfall model

Traditional

A linear and sequential approach where each phase must be completed before the next begins. It is straightforward but less flexible in accommodating changes once the project is underway.



- Simple and easy to use
- Easy to assign tasks to specific person
- If requirements are cleary defined
- Each phase is processed at a time

- No change in requirements
- No overlapping phases
- Lack of flexibility
- Not ideal for complex projects
- No feedback path

https://bap-software.net/en/knowledge/what-is-the-waterfall-software-models/

Waterfall model

BME Automotive Technologies

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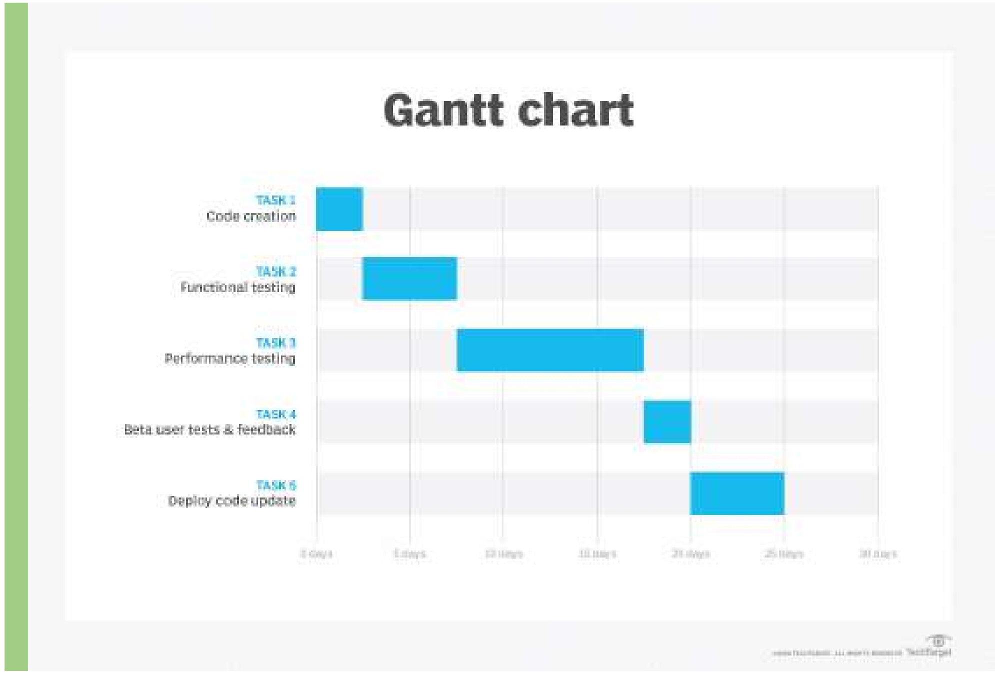
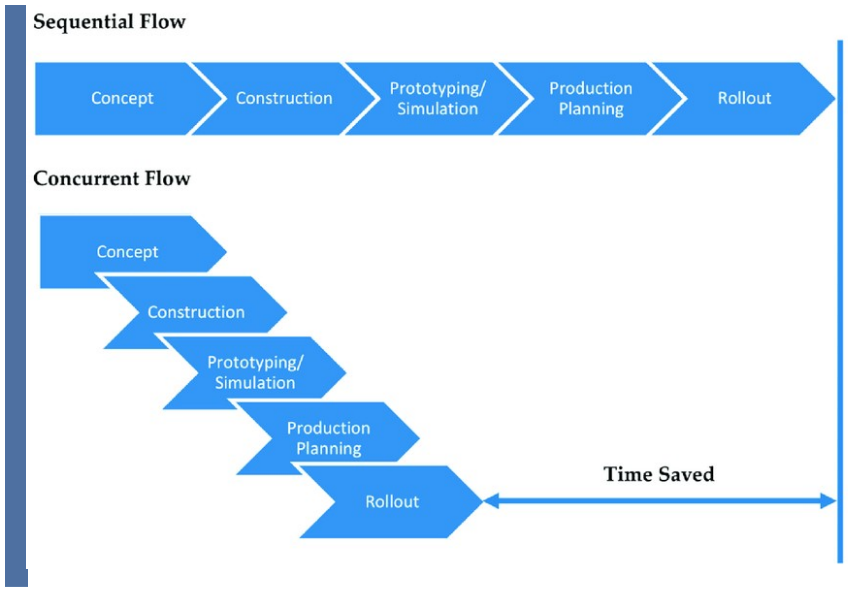
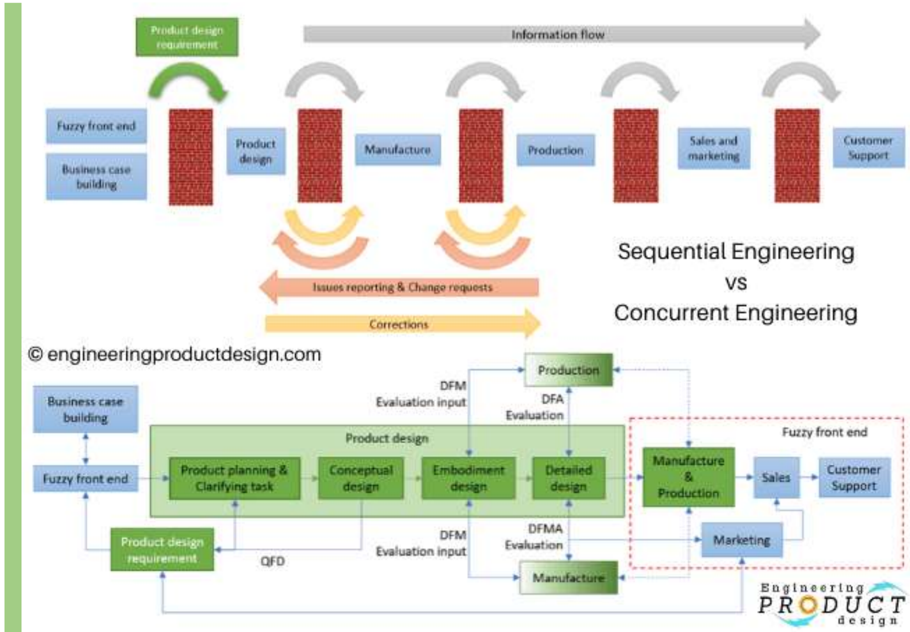


https://www.techtarget.com/searchsoftwarequality/definition/waterfall-model

Concurrent Engineering

- **Concurrent engineering** is a systematic approach to integrated product development that emphasizes the parallelization of tasks (i.e., performing tasks concurrently) to reduce the time to market.
- **Principles:**
  - Early involvement: to engage all relevant disciplines;
  - Integrated teams:use cross-functional teams to ensure that all perspectives are considered throughout the development process;
  - Paralell tasks: perform multiple development activities simultaneously rather than sequentially;
  - Iterative process: Countinously iterate and refine designs based on feedback from all team members and stakeholders.

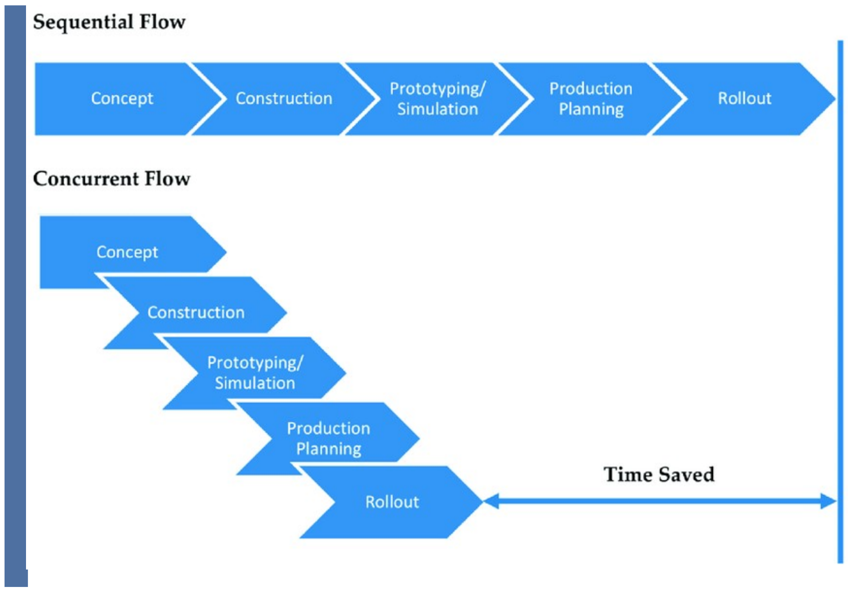


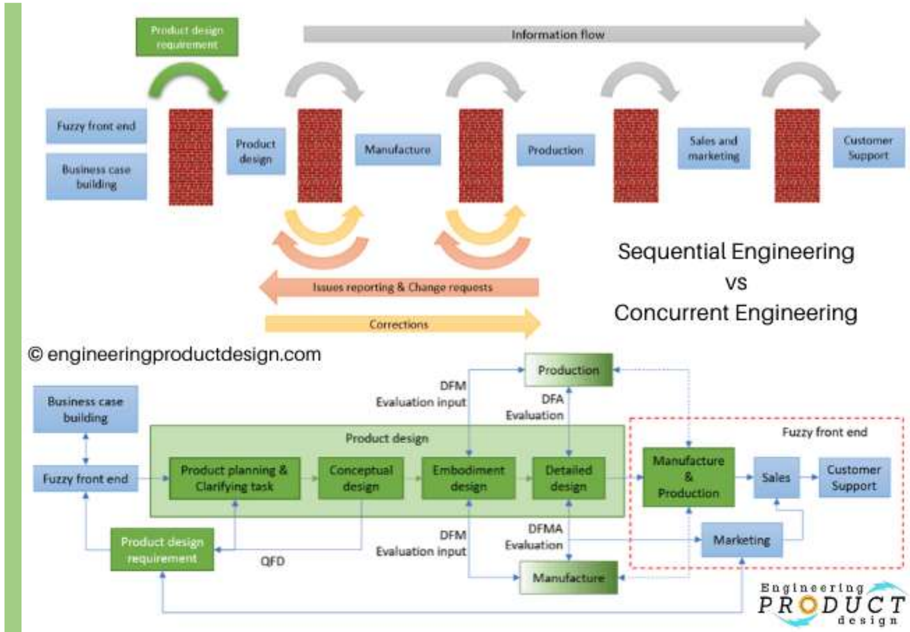


https://engineeringproductdesign.com/knowledge-base/concurrent-engineering/ ; https://www.researchgate.net/figure/Time-savings-due-to-Concurrent-Engineering-based-on-Reference-20_fig1_333021534 ;

Concurrent Engineering

- **Advantages:**
  - **Reduced time to market** – by overlapping tasks
  - **Improved product quality** – enchanes design by incorporationg feedback from multiple disciplines early and often
  - **Cost efficiency**
  - **Enhaced collaboration**
- **Challenges:**
  - **Coordination complexity** – requires effective coordination and communication among diverse teams
  - **Resource allocation**
  - **Cultural change** – may require shift in organizational culture





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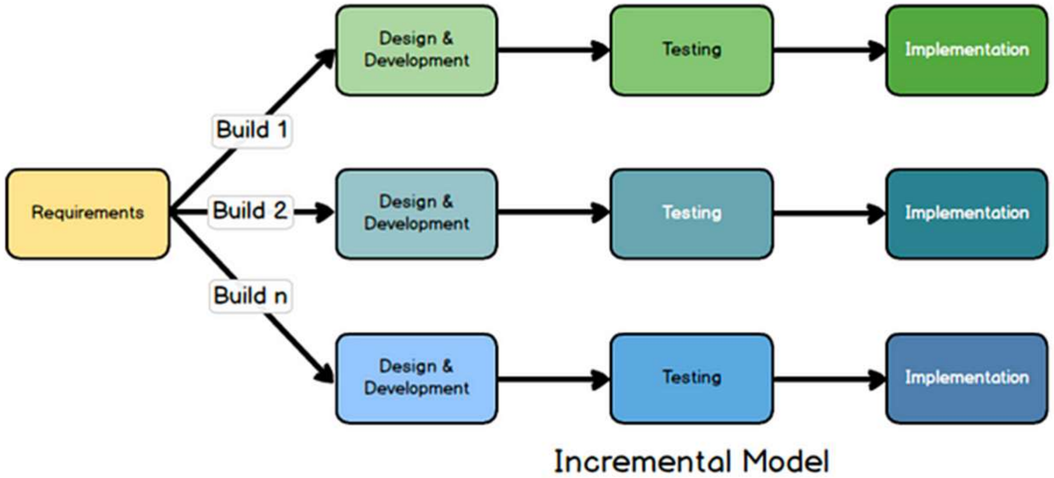
Incremental model

Traditional

The incremental model is an iterative software development approach where the product is designed, implemented, and tested incrementally (in portions) until the product is complete. Each iteration builds upon previous functionality, allowing for early delivery of parts of the system and incremental improvements based on user feedback.

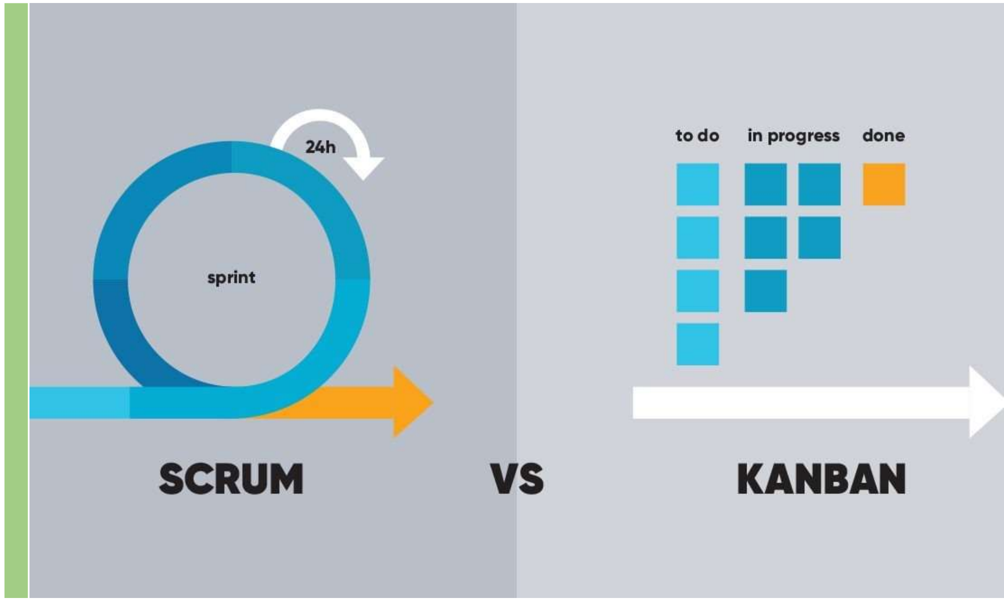


https://bootcamp.uxdesign.cc/dlc-software-development-model-incremental-development-7598ae6500e6

Agile methodologies

Agile

Focus on iterative development and continuous feedback. Agile approaches, such as Scrum and Kanban, are adaptive and promote flexibility, making them suitable for projects where requirements evolve over time.



Recommended:
https://www.youtube.com/watch?v=502ILHjX9EE

https://www.wesquare.nl/scrum-vs-kanban-a-fair-comparison/

Agile methodologies

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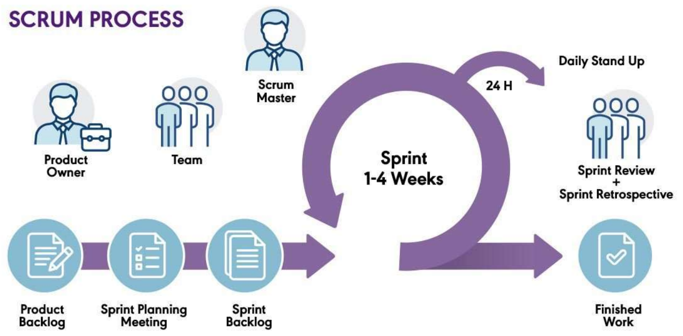
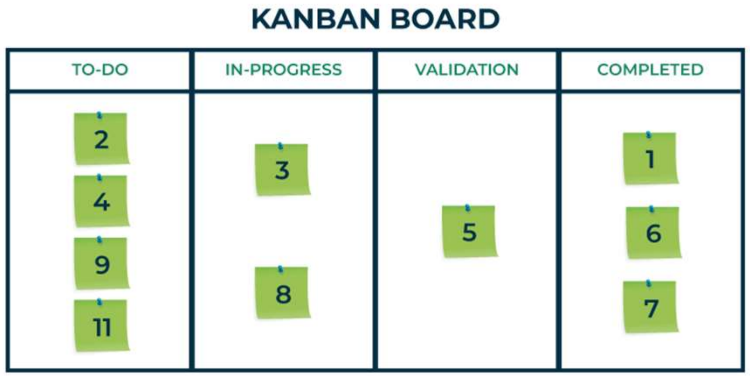


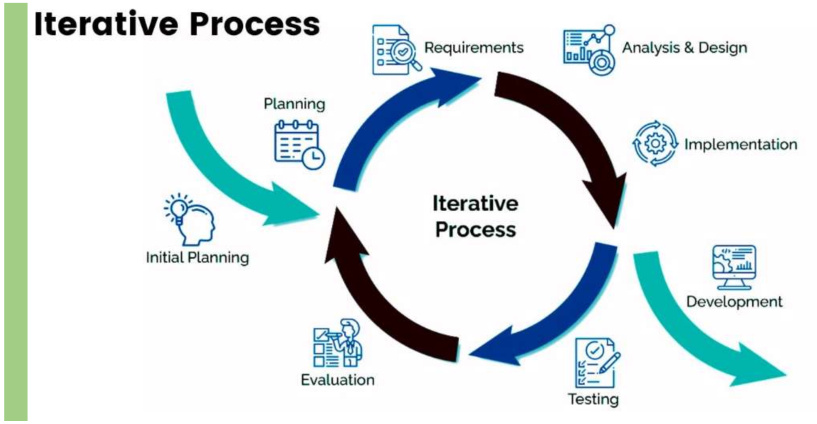


https://www.wesquare.nl/scrum-vs-kanban-a-fair-comparison/

Iterative processes

Agile

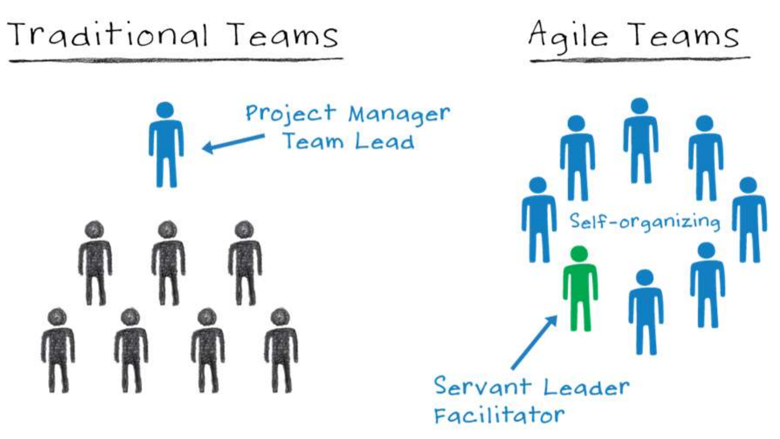
Iterative design is a cyclical process of prototyping, testing, analyzing, and refining a product or process. Allows for continuous improvement and adaptation based on feedback and testing results.

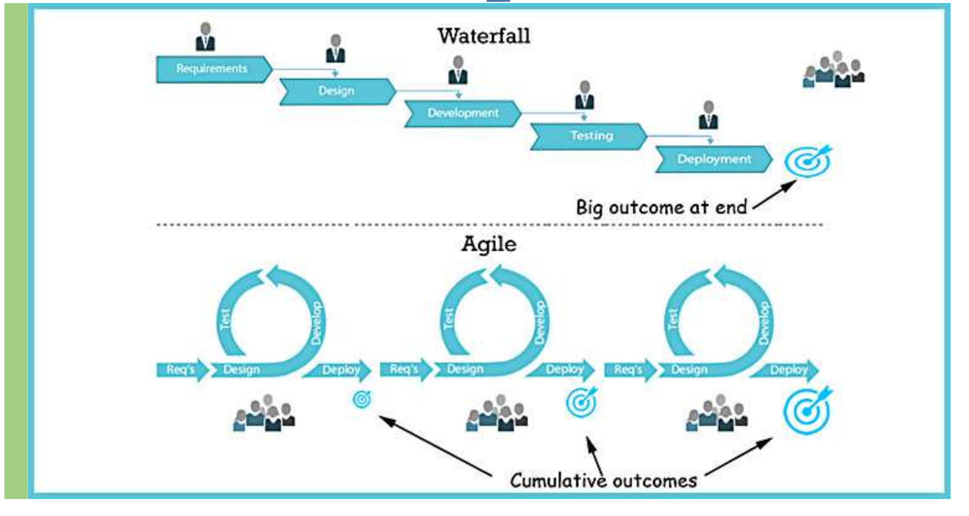


https://www.timetrackapp.com/en/blog/iterative-process-definition/;

Choosing the right methodology

- Factors to consider:
  - Project size
  - Complexity
  - Stakeholder analysis
  - Teams expertise
- Visuals:
  - Decision matrix or flowchart for selecting

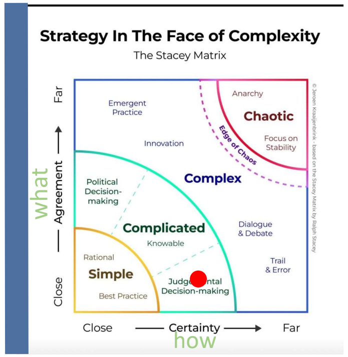


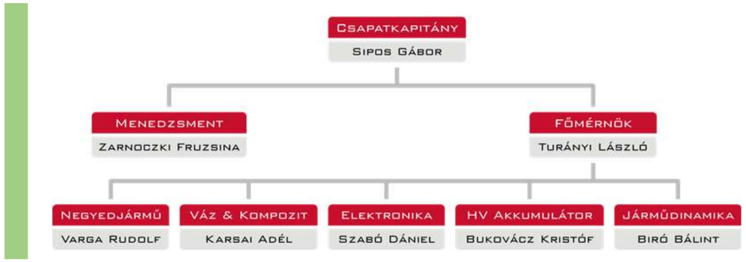


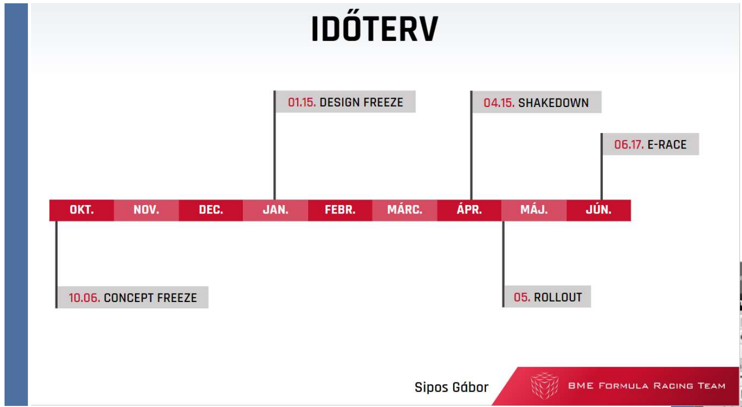
https://www.mindk.com/blog/agile-vs-waterfall/ ; https://www.linkedin.com/pulse/transforming-from-waterfall-agile-iqbal-ismailwala-/ ;

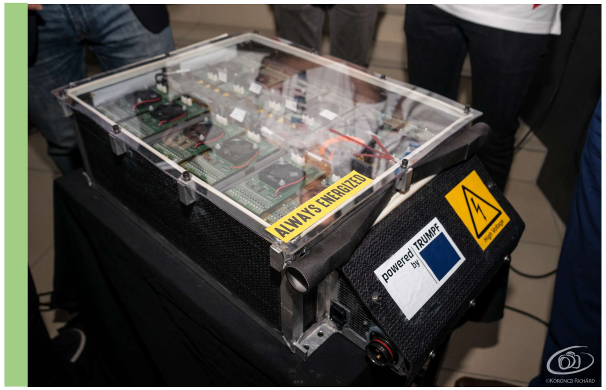
Case studies and examples

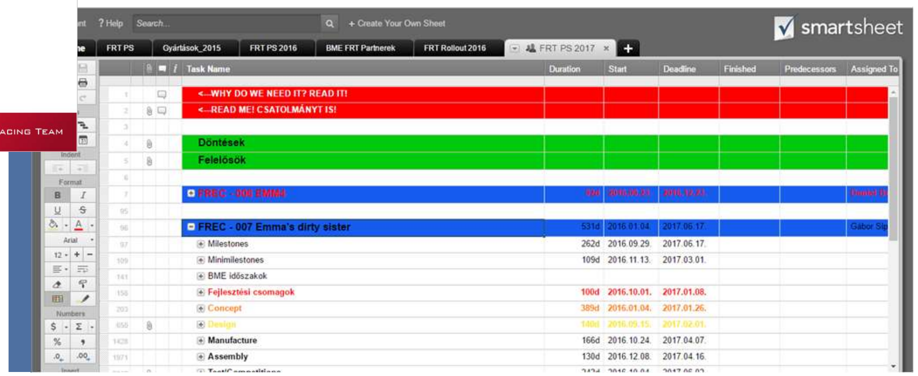
- BME Formula Racing Team – Formula Student
  - Project size – 35-60 university students
  - Complexity – What? – we knew | How? – mid/far -> Complicated
  - Stakeholder analysis -
  - Teams expertise – low, unexperienced engineers and managers











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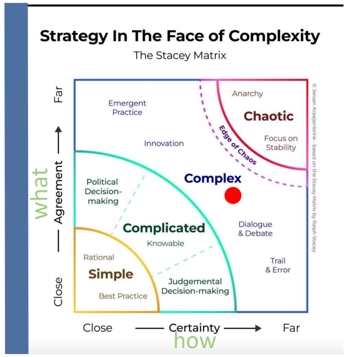
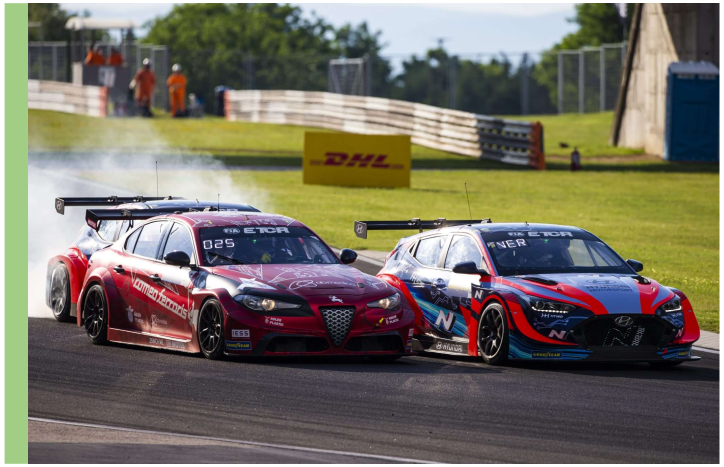
Case studies and examples

- WSC Ltd. – Development of ETCR
  - Project size – 5-6 Key supplier, 4-5 Manufacturer
  - Complexity – What? – mid/far | How? - mid/far -> Complex
  - Stakeholder analysis – Manufacturers, Suppliers, Promoter, Customers
  - Teams expertise – high, but new field

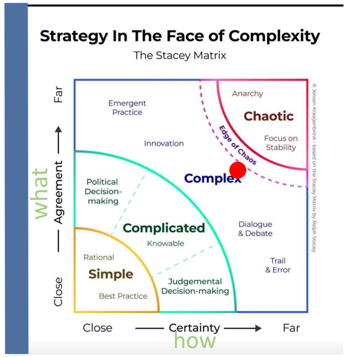


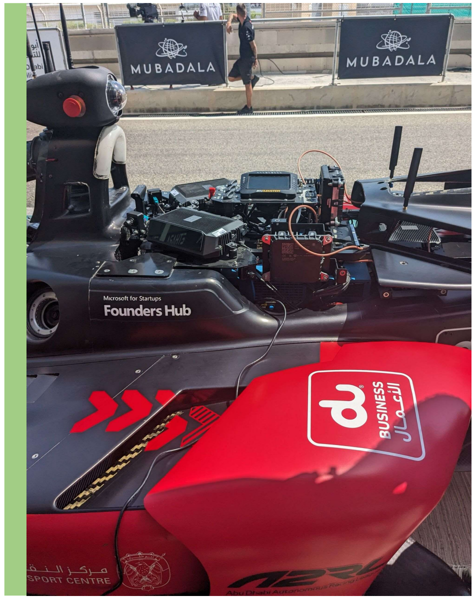


https://electric-tcr.com/zh/newsetcr/item/the-battery-integration-was-completed-in-the-giulia-etcr ; https://www.fia.com/news/technology-fias-maiden-electric-touring-car-series ;

Case studies and examples

- HUMDA LAB NKft.– Development of A2RL driver
  - Project size – Development 20 people | Testing +operation team
  - Complexity – What? – mid/far | How? - mid/far -> Complex
  - Stakeholder analysis – Development: dev team
  - Teams expertise – high, but new field



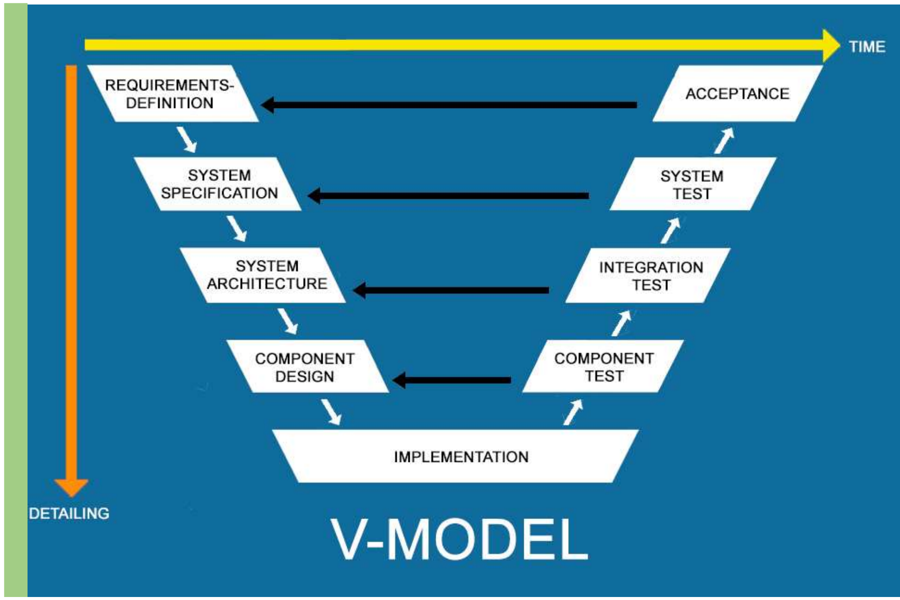


A2RL
Abu Dhabi Autonomous Racing League

https://arstechnica.com/cars/2024/05/driverless-racing-is-real-terrible-and-strangely-exciting/ ; https://www.automotor.hu/sport/5-helyen-zart-a-humda-lab-az-abu-dhabi-autonomous-racing-league-onvezeto-autoversenyen/ ; https://www.the-race.com/single-seater-open-wheel/what-happened-in-first-a2rl-autonomous-race/

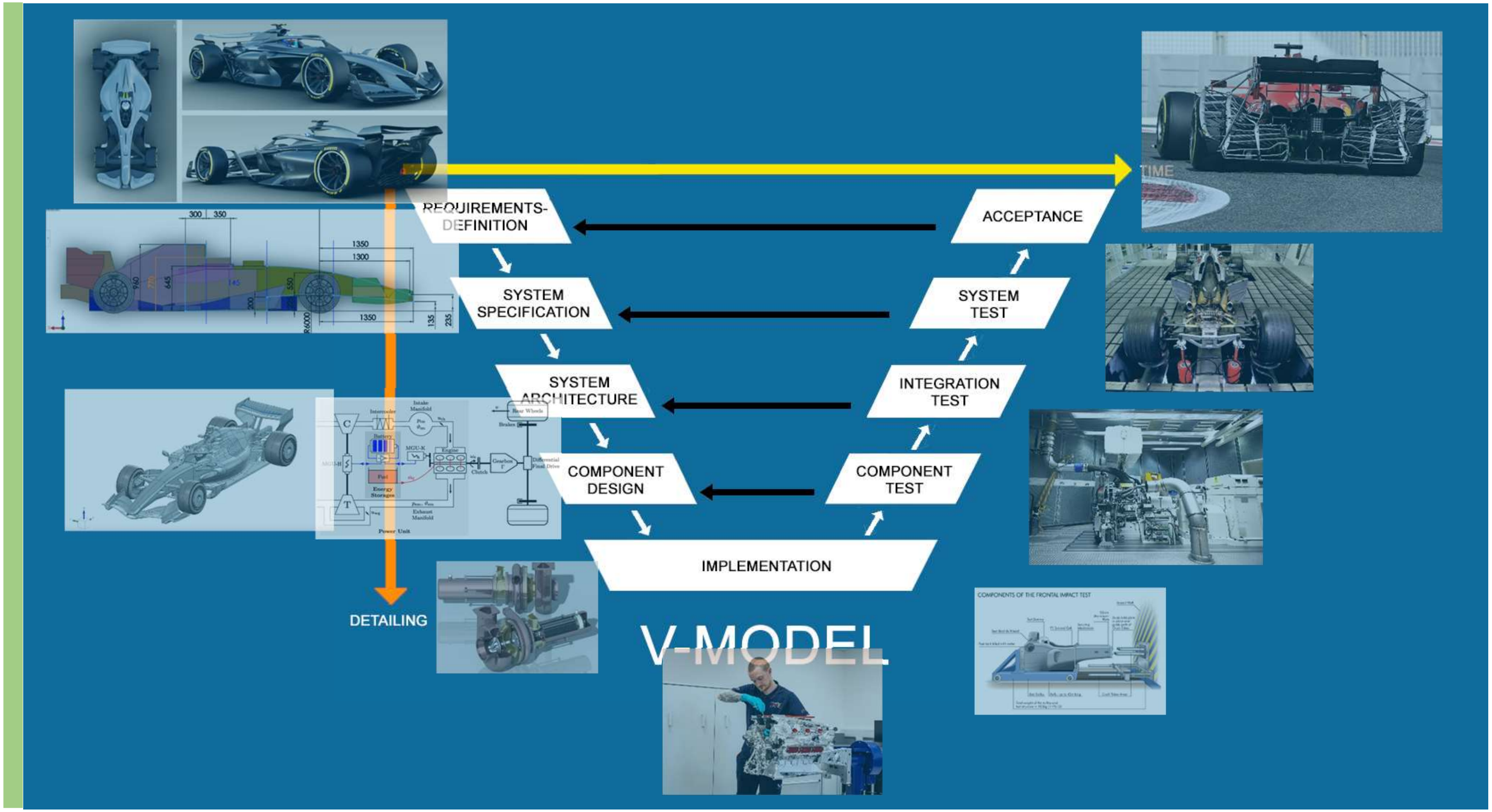
V-model

The V-Model is a widely used development process model that illustrates the relationships between each phase of the development life cycle and its associated phase of testing. It's called the "V-Model" because the diagram of the process looks like the letter "V„ (Verification & Validation)



https://t2informatik.de/en/smartpedia/v-model/

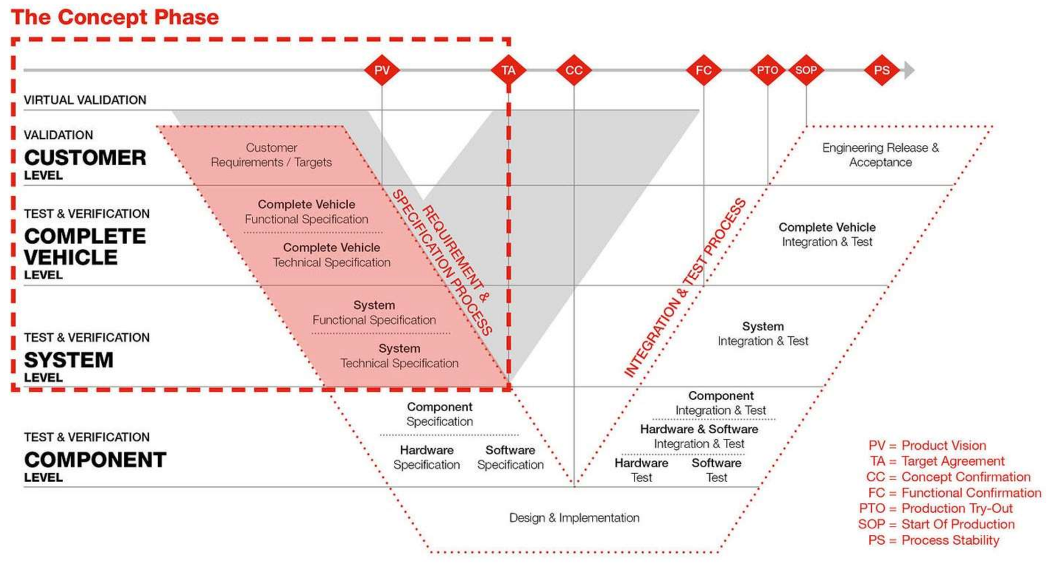
V-model



https://www.mdpi.com/1996-1073/14/1/171; https://www.racecar-engineering.com/articles/tech-explained-2022-f1-technical-regulations/ ; https://www.pmw-magazine.com/news/race-series-news/fia-reveals-details-of-2026-f1-regulations.html ; https://formula1technical.weebly.com/articles/2014-f1-car-fia-safety-equipment-testing ; https://ehfcv.com/hardware-in-loop-hil-simulation-formula-1-racecar/

V-model

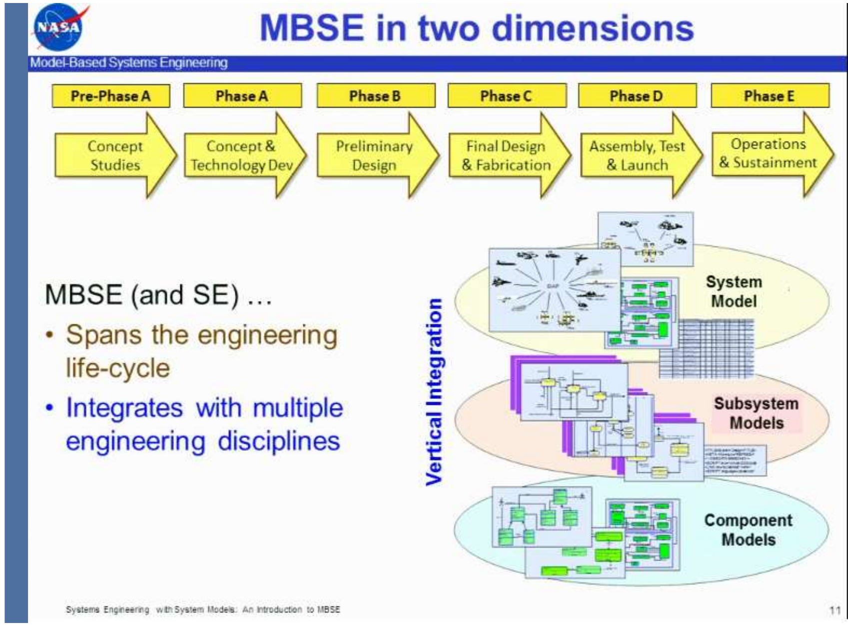
- **Sequential Phases:** Each phase must be completed before the next one begins. This is similar to the Waterfall model but includes corresponding testing activities for each development stage.
- **Validation and Verification:** The left side of the V represents the stages of verification (planning, requirements, architecture design, detailed design, and implementation), while the right side represents validation (unit testing, integration testing, system testing, and acceptance testing).



https://www.magna.com/stories/inside-automotive/concept-creation/new-car-development-process

Model-Based Systems Engineering (MBSE)

- **MBSE** is part of SE
- **MBSE** is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.
- **MBSE** uses model as an integral part of the technical baseline

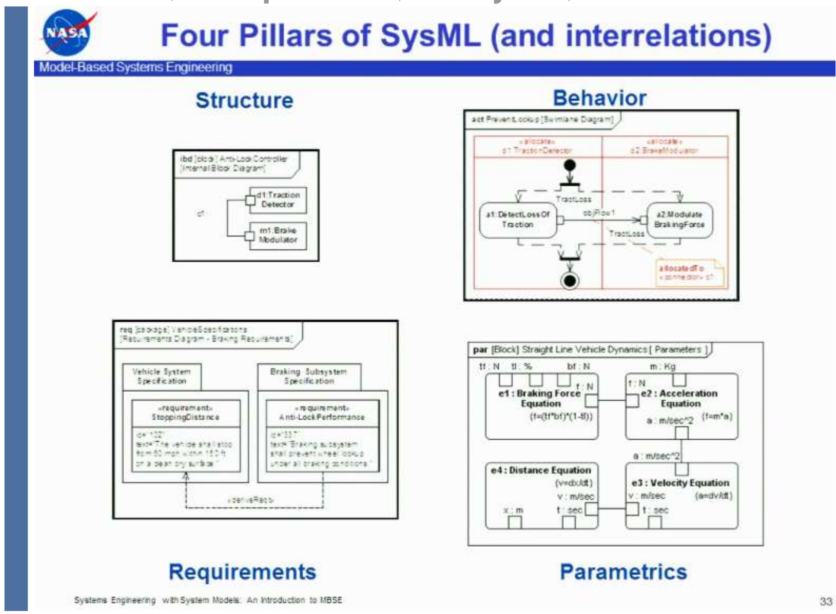


https://nescacademy.nasa.gov/video/804f524f16c24fd2927a4eb9f01bdf831d

https://www.magna.com/stories/inside-automotive/concept-creation/new-car-development-process

Model-Based Systems Engineering (MBSE)

- **SysML^{TM}:** Systems Modeling Language, general-purpose modling language that supports specification, design, analysis and verfication of systems that may include hardware, software, data, personnel, procedures, and facilities.
- **Structure:** Structural composition, Interconnection, Classification
- **Requirements:** Requirements, Relationships to other requirements, interfaces, components, analyses, and test cases
- **Behavior:** Function-based, Message-based, State-based
- **Parametrics:** Constraints on physical and perofrmance properties



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Design for X (DfX)

BME Automotive Technologies

- **Definition:** Design for X (DfX) refers to a set of design principles aimed at optimizing specific attributes or characteristics of a product. The "X" represents various aspects such as manufacturability, assembly, reliability, etc.
- **Purpose:** To improve various aspects of the product lifecycle, ensuring enhanced performance, quality, and cost efficiency.

Pro: Improved product quality, cost savings, faster time to market, enhanced customer satisfaction

Cons: Complex trade-offs, initial investment, cross-disciplinary collaboration

Meets specific customer needs and expectations by focusing on critical attributes.

https://www.youtube.com/watch?app=desktop&v=REIB2_VKPJw ;

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	DfM	DfA	DfR	DfC	DfS
Aim	Simplifying manufacturing process	Simplifying assembly process	Ensuring the product functions reliably over its intended lifecycle.	Reducing the overall cost of the product.	Minimizing the environmental impact of the product.
Key points	Reducing nr of parts, standardizing materials, minimizing complex features	Reducing the number of assembly steps, using self-locating parts, and designing for ease of part handling.	Using robust materials, incorporating redundancy, and conducting thorough testing.	Optimizing material usage, simplifying the design, and improving production efficiency.	Using eco-friendly materials, designing for energy efficiency, and facilitating recycling.

Design for X (DfX)

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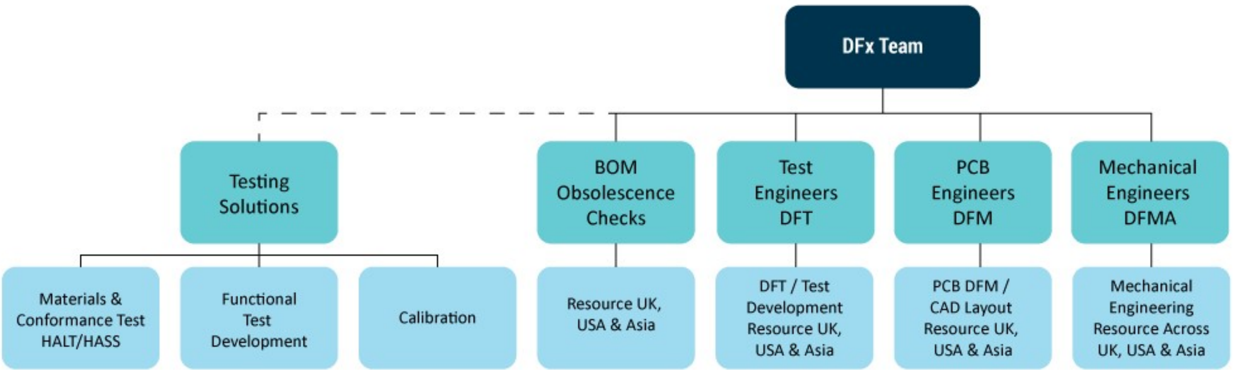


Traditional Engineering vs DFX

Traditional Engineering Design	Designing for Excellence (DFx)
Address issues after the design phase	Address issues at early design stage
Many iterations of a product	Goal is to limit iterations (get it right the first time)
Use of many tools	Select use of an efficient set of standardized tools
Considers functional requirements	Considers the product life cycle requirements
Less team based (less involvement from manufacturing, suppliers and customers)	Team based (more collaboration, supplier involvement, project management)

#work in delta

Highly recommended content:https://www.ttelectronics.com/blog/design-for-excellence/

https://www.ttelectronics.com/blog/design-for-excellence/

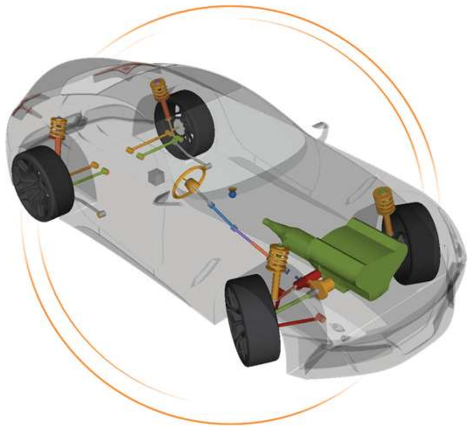
Design for X (DfX)

- **Tools and Techniques:**
  - Failure Modes and Effects Analysis (FMEA): Identifies potential failure modes and their impact on product performance
  - Value Engineering (VE): Analyzes the functions of a product to improve value by either improving function or reducing cost.
  - Design of Experiments (DOE): Systematically tests different design variables to optimize product performance.
  - Computer-Aided Design (CAD) and Simulation tools: Use software to model and simulate different design attributes.

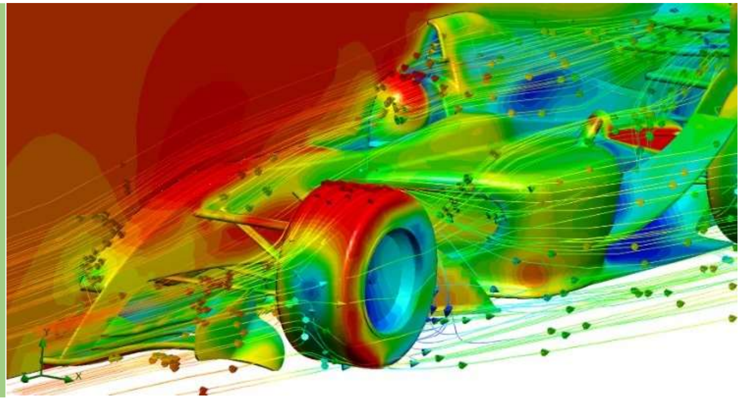
https://www.ttelectronics.com/blog/design-for-excellence/

Simulation and Digital Twin Technology

- **Simulation:** Simulation is the process of creating a virtual model of a physical system to study its behavior under various conditions. Purpose is to analyze and predict the performance, efficiency, and reliability of a system without physical prototypes.



- **Types (*computer aided analysis*):**
  - **FEA – structural & thermal**
  - **CFD – fluid flow and heat transfer**
  - **MBD – movement and interaction of interconnected bodies**



https://advanced-eng.cz/reseni-a-sluzby/multi-body-simulation ; https://www.linkedin.com/pulse/computational-fluid-dynamics-cfd-finite-element-fea-rahul-krishnan/ ;

Simulation and Digital Twin Technology

BME Automotive Technologies

FEA	CFD
Simulating and analyzing solid mechanics problems	Fluid dynamics
Linear/nonlinear, static/dynamics, thermal and multi-physics	Laminar/turbulent flow, transient/steady state, multi-phase
Aerospace, automotive, civil engineering	Aerospace, automotive, chamical, power generation
Stress, strain, deformation, vibration	Fluid flow, heat transfer

Heat Transfer mechanisms	FEA	CFD	Either	Notes
Conduction only	X			No need to simulate fluid flow
Conduction w/ Predictable Convection			X	Faster with FEA. Need to know convection coefficients
Conduction w/ Unpredictable Convection		X		
Conduction, Radiation w/ Predictable Convection		X		FEA not practical
Conduction, Radiation w/ Unpredictable Convection		X		

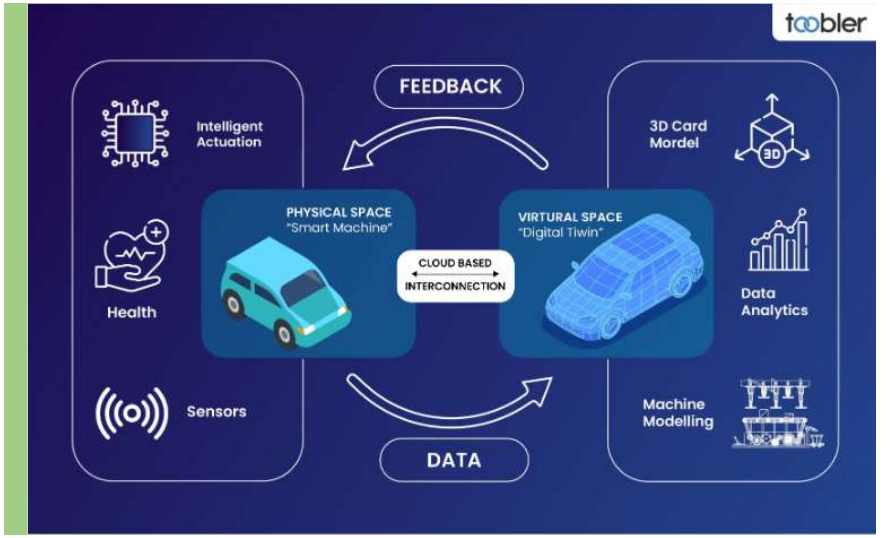
https://my.solidworks.com/reader/wpressblogs/2017%252F04%252Fuse-fea-vs-cfd-thermal-analysis.html/when-to-use-fea-vs-cfd-for-thermal-analysis;

Simulation and Digital Twin Technology

- A digital twin is a virtual representation of a physical product, system, or process that is used to analyze and optimize its performance throughout its lifecycle. Real time model that reflects to the actual state of the physical counterpart.
- **Parts:** Physical, Virtual and Data connection

Examples:
  - Predictive maintenance
  - Optimization of performance
  - Enhanced decision making
  - Lifecycle management

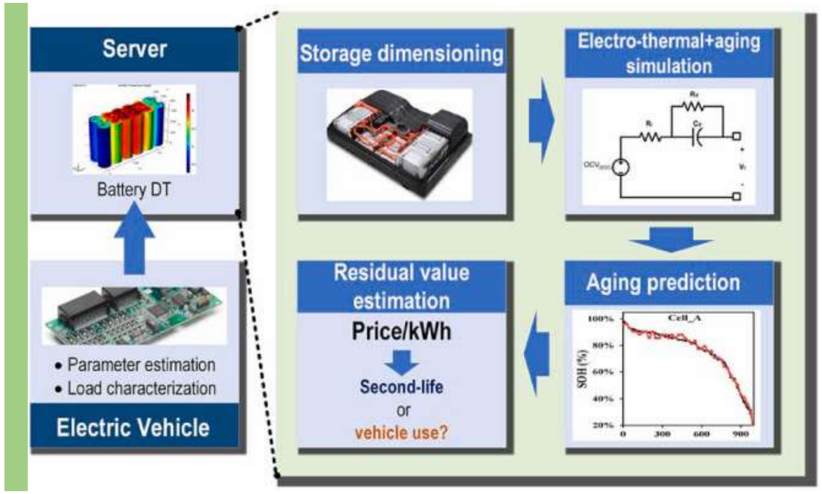
Key areas:
  - Vehicle health monitoring
  - Manufacturing optimization
  - Product development

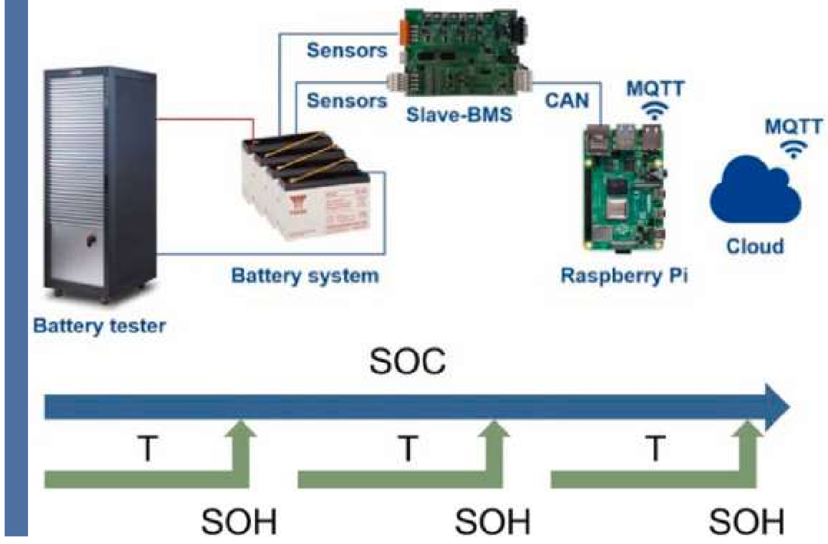


https://www.toobler.com/blog/digital-twin-iot ;

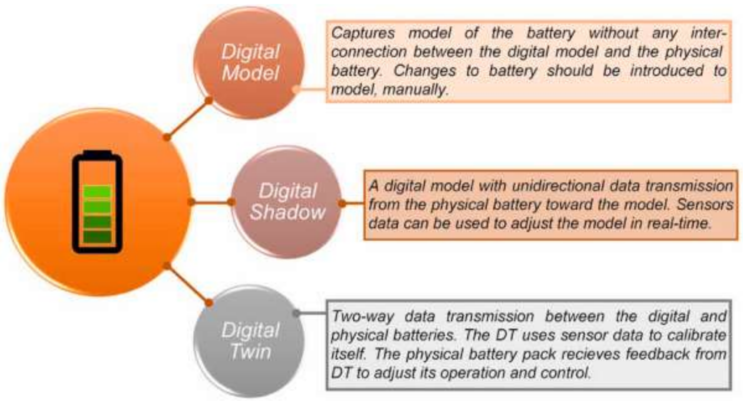
Simulation and Digital Twin Technology

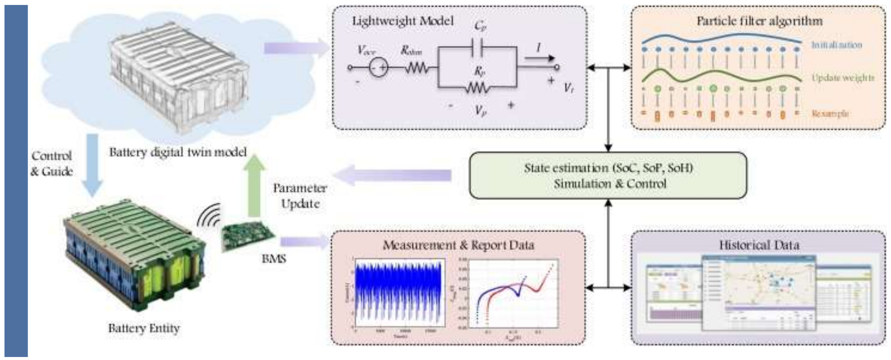
- Example – digital twin





Performance optimization	Awareness about future health allows optimization of operations, e.g. by changing the operating limits to de-risk failures.
Predictive maintenance	Optimized maintenance reduces downtimes and improves safety and reliability.
Second-life planning	Helps to know when the batteries should be retired and this information can be useful for planning re-use or replacement.
Guaranty/Warranty	Support of warranty claims against cell/module/pack providers.
Fleet management	Enabling informed decision systems for maintenance, management, and replacement of the EV fleet.

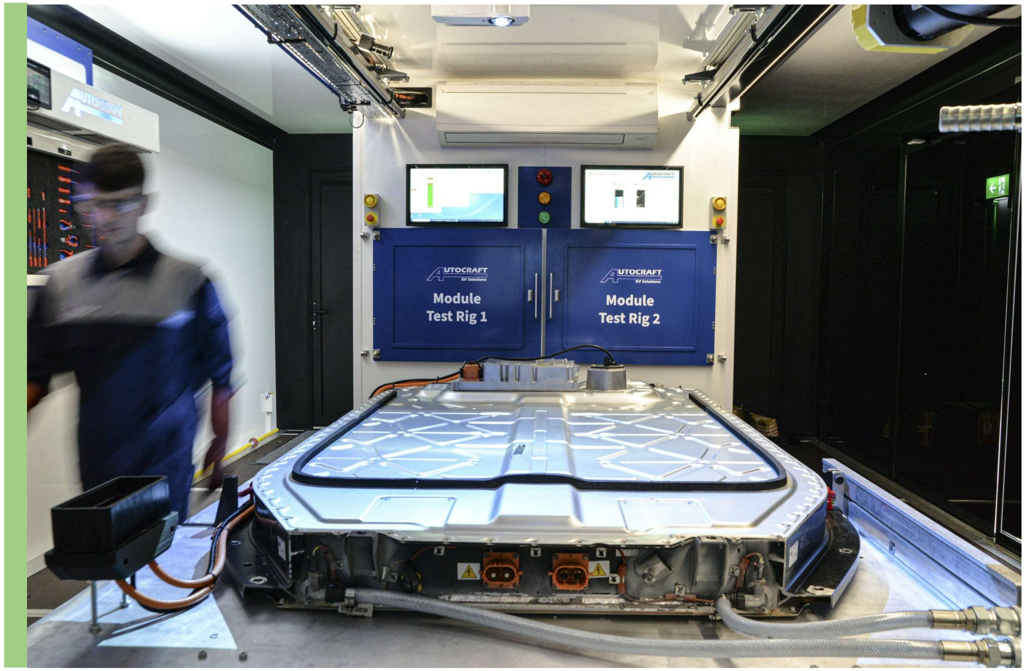


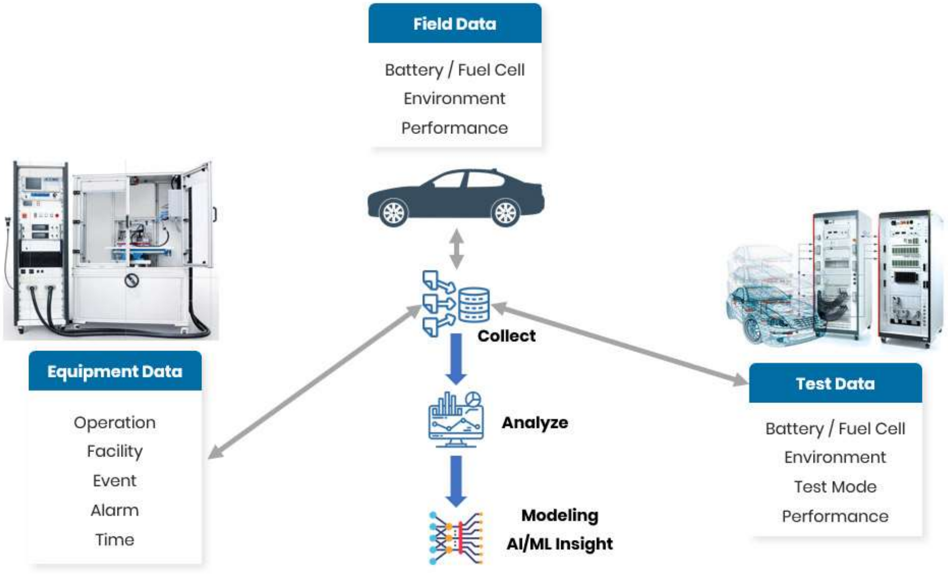


https://www.sciencedirect.com/science/article/pii/S1364032123001363 ; https://www.sciencedirect.com/science/article/pii/S0278612521002284 ;

Simulation and Digital Twin Technology

- Example – digital twin





https://autocraftsg.com/news/insights/how-can-the-use-of-digital-twins-support-optimal-ev-battery-health/ ; https://tenergy.co.kr/business_area_11.php ;

Prototyping and Rapid Prototyping

- **Definition:** Prototyping is the process of creating a preliminary model of a product to test and validate design concepts before final production.

- **Purpose:** To explore and visualize design ideas. To identify and resolve design issues early. To gather feedback from stakeholders and users.

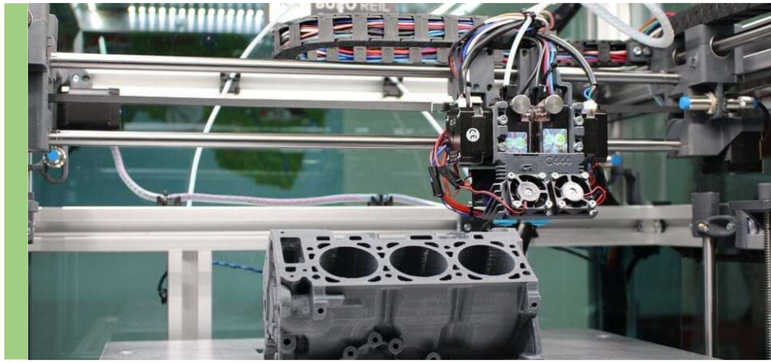
- Types:
  - Low-Fidelity: skecthes, simple models. Early design phases. Quick and cheap.
  - High-Fidelity: Detailed and functional models. Closer to the final product in terms of appearance and functionality. More advanced testing and validation.

- Rapid Prototyping techniques: 3D printing, CNC Machining

- Application: Design validation, User feedback, Functional testing, Marketing and demonstration

- Pro: Early detection of issues, Improved communication, User- centered design, Innovation

- Cons: Resource intensive, Over reliance, Incomplete testing



https://www.shapr3d.com/blog/rapid-prototyping-evolves-into-multiple-processes ;

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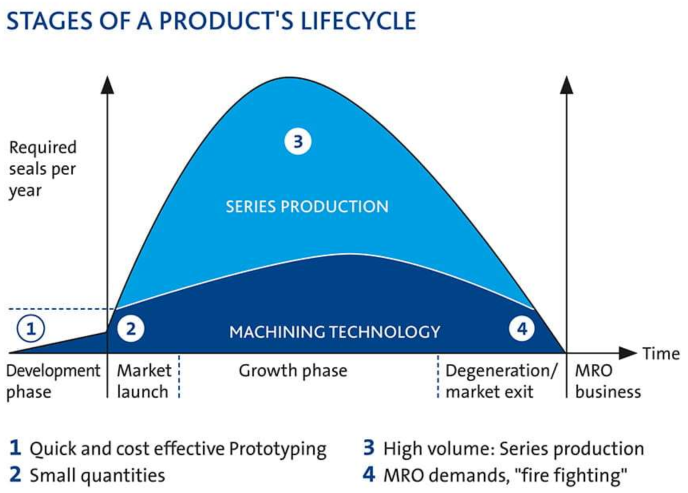

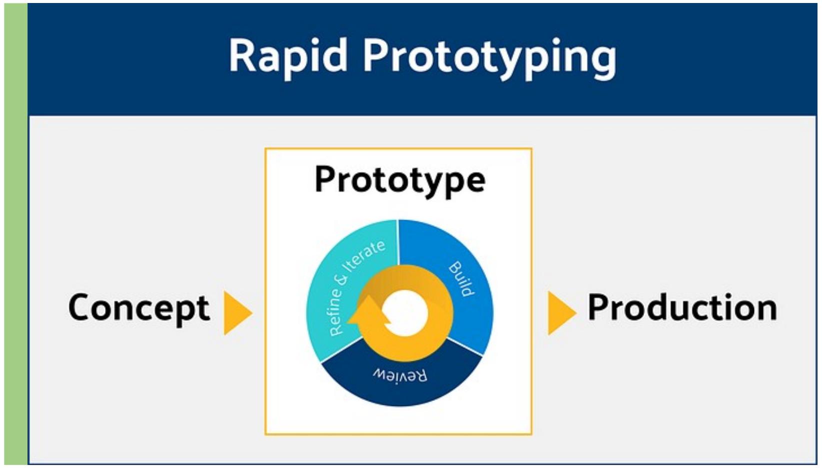

https://medium.com/@designgrapes/designing-for-rapid-prototyping-how-to-effectively-test-your-rack-2f688ff2d2f ; https://www.fst.com/services/machined-seals/rapid-prototyping-and-customized-production/ ;

Q & A

- Main objective?
- Starting point-ending point?
- Complex parts?
- Less relevant part(s), could be omitted part(s)?
- Most useful part(s)?

Closing

- Bibliography
  - See bottom of slides
- Literature
  - W. Ernst Eder: Engineering Design: Role of Theory, Models, and Methods
  - Julian Weber - The Automotive Development Process: Processes for Successful Customer Oriented Vehicle Development
  - Markus Maurer, Hermann Winner - Automotive Systems Engineering
  - Christian Grönroos - The V-Model of Service Quality: An Application in Automotive Services
  - Gerhard Pahl, Wolfgang Beitz - Engineering Design: A Systematic Approach
  - Jiju Antony - Design of Experiments for Engineers and Scientists
  - Dominic Haider - Automotive Functional Safety: A Complete Guide to ISO 26262
  - Bercsey Tibor - A terméktervezés módszertana.Jegyzet
  - Pahl-Beitz - A géptervezés elmélete és gyakorlata


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Thank you for your attention!