«Systems Engineering»-Guidelines

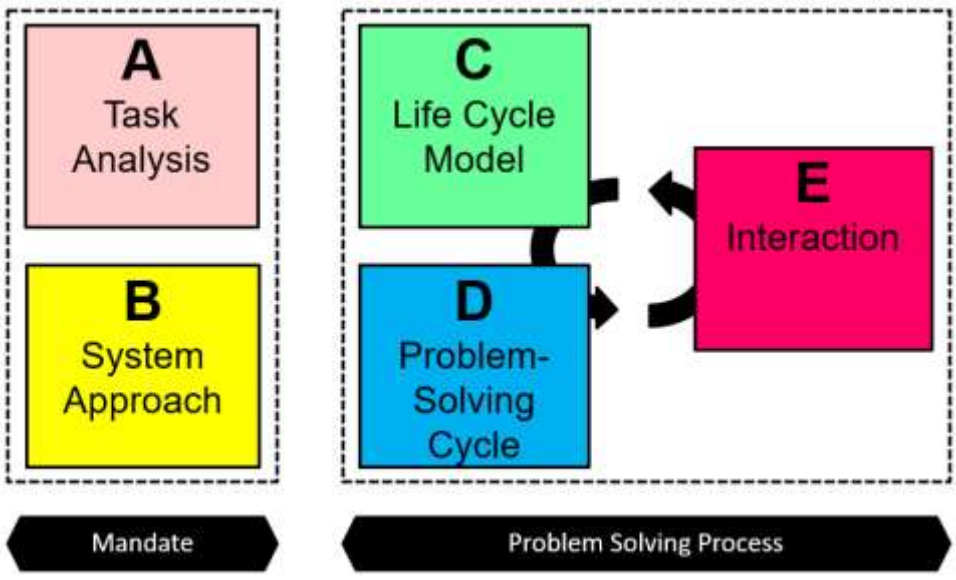
A framework for systematic problem solving
in the fields of Engineering and Management
Based on «Systems Engineering»[1]

The systematic design of complex socio-technical systems in interdisciplinary working project teams requires an appropriate problem solving process; the methodology “Systems Engineering” provides the necessary knowledge.

With the growing complexity in Engineering and Management the need of a comprehensive methodology with effective planning principles arises. As a consequence, researchers at ETH Zurich developed the methodology called “Systems Engineering”.

The experiences of many years as a -lecturer and project coach in different projects show that the practical application of “Systems Engineering” is often a problem. Therefore, for project managers who would like to apply “Systems Engineering” the present framework provides easy to handle guidelines.

The frame for practical appliance contains five worksheets:



[1] *Züst, R., Troxler, P.: No More Muddling Through, Mastering Complex Projects in Engineering and Management, Springer, Dordrecht, 2006. ISBN: 978-1-4020-5017-6*

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A Task Analysis:
Motivation and expectations of the employer…

		existing	*answers / comments*
Information about the System	*A1: Initiation of the project*		
	A2: describe the required solution as a system		
	A3: scope of the new design		
	A3: important aspects		
	A4: important influences		
	A5: critical elements		
	A6: people involved and affected		
Expectations	*A11: present requirements*		
	A12: expected benefit		
	A14: interface to other projects		
	A15: link to similar projects		
Ideas for the procedure	*A21: project manager / project team*		
	A22: milestones / deadlines; interim and end decisions		
	A23: type and extent of the deliverables		
	A24: expenditure (money, time)		
	A25: steering committee / contact person		

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B System description and system boundary: describe the situation as a system...

B1: Systems are more than the amount of elements…

Formulate the expected «product» / the new solution as a system!

Example: A new and more intelligent refrigerator will become a «Smart food storage and delivery system»; the investigation area is now broader, and the mandate is formulated in a "solution-free" way!

(compare: A1, A2)

B2: Influence analyses – which influences affect the system / part of the system?
System environment – which part is relevant for the planned improvement?

The new solution / the new system should fit into the future environment – therefore, the environment of the system and the influences have to be analysed in detail.

Example «new production system» - influences on the new solution are among other things: lows / standards, production jobs (part, number of part, single shift or not, …), technology trends, competitors, competitor's products, present production infrastructure, …)

(compare: A3, A4, A5, A14, A15)

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B3: **System and part of systems:** Which are the relevant parts of the system?

Example «Steel plant» - parts are amongst others: buildings, ? foundations, continuous casting facility, transportation infrastructures / cranes, energy supply, …

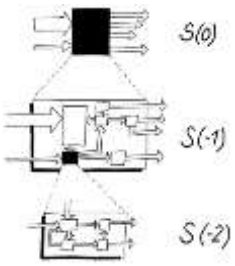
How the elements are associated? Keyword: process model(s), input-output-models, value stream mapping, …

In addition: Might an aspect-oriented view be successful?
Example: material flow, energy flow, information flow, …

(compare: A3, A5)

Three pieces of advice:

1. Avoid obvious, quasi «natural», striking, conventional system boundaries; these are often not good!
2. Scrutinize each boundary carefully! Do this in every planning step!
3. Black-boxes, aspect-oriented analysis and the principle of hierarchisation might support the process of defining system boundaries.



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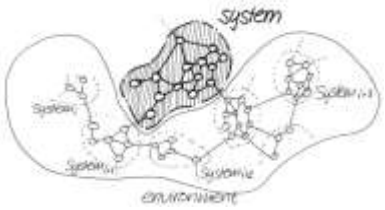
B4: **System boundary**:
What can / what should be optimized? What is the scope?

Example «new production system» - is it possible to demolish the current building? Is there a restriction to design anew production system in the present infrastructure? Or is it possible to design a new production plant (="green-field site")?

Note: the system contains only the system elements which can be changed / optimized (area of the new design); outside of the system is the environment which cannot be changed in the project. Therefore, the system boundary should be discussed with the employer.

Advice: take in account B2 and B3; compare: A6, A14, A15



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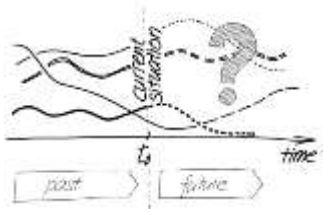
B5: **Considering time-related changes**:
Which changes are possible / feasible? What can be the behaviour of the system Which might be the effects?

Example “new production system”: What are the trends? Which are the external influences (for example: late delivery of material) and which are the effects in the production system (lower productivity, more intermediate stores, higher cycle time, …)

Advice: analyse the future trends in the environment of the system carefully; an FMEA-analysis could be helpful.

Show possible trends; take into account the behaviour of other people (involved or affected). Show possible changes and evaluate their relevance!

Is it indicated to change / to adapt the system boundary?



B6: **Ensure the development of an effective overall system** – how should the integration for different system aspects be done / be achieved

Advice: plan a regular balance of the different system elements - keyword: breakpoint and synchronisation!

(compare: A14, A15, A22)

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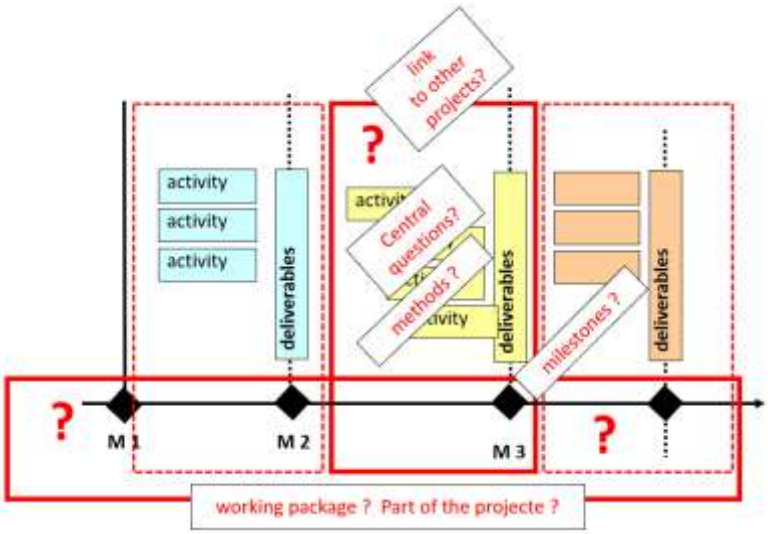
C Problem solving strategy:
structure the procedure in an effective way…

Structure your procedure in suitable parts and working packages; use the so-called «life-cycle model» as a framework.

Document each working package:

- which are the central questions to be answered,
- how to proceed in a systematic way,
- which are the required deliverables after every working package and how to check these results, and
- which are the links to other projects

In addition: show how to secure the design of an effective overall system (compare: B6).



Part of the project(e)

In the development phase the system / the solution will be designed step by step, from a general overview to the detail, from a rather abstract design to a concrete solution. Within «Systems Engineering», the development phase is divided into four life-phases:

- proposal for systems design,
- preliminary study,
- main study, and
- detailed study.

For every task / project it is recommended to check with the employer where the project starts and after which life-phase the project ends. This depends on what has already been done and what the employer would like to achieve. It is often advisable to divide the problem solving process into separate steps.

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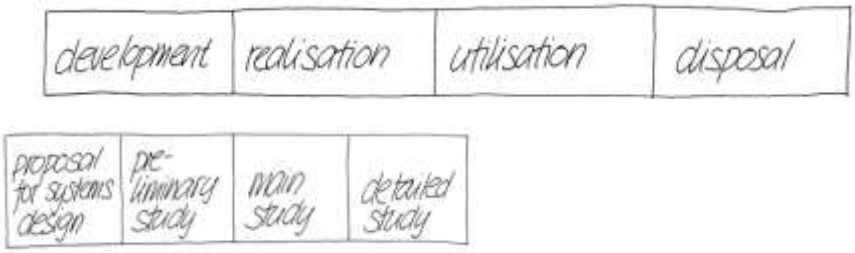
C1: **Where is the starting point of the project?**
What has already been done? What has already been documented?

Example: the main decision has already been taken– the employer would like to have a concept with detailed economical investigations for a new production system. If neither the principle solution is known nor the concept – a partition into «preliminary study and main study» is recommended.

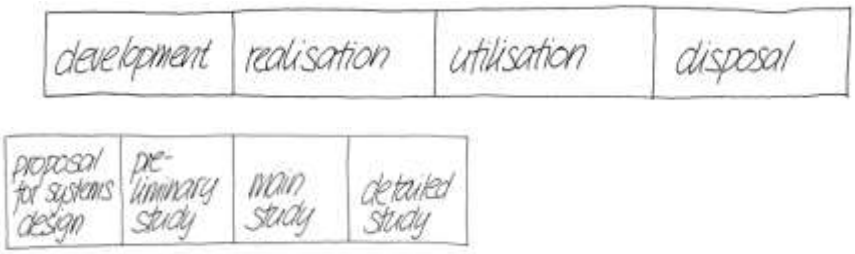
What is the starting point of the project? Why this assumption?

Determine the starting point and give some explanations!



What will be result at the end of the study? Why these assumptions?

Determine the end point of the project and give some explanations!



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C2: **Is it indicated to work on a «proposal for systems design»? What is missing?**

Further analysis is required if there is no final decision by the employer to deal with the problem within the scope of the project. See below some questions to be answered:

Questions	***answers***	
	Yes / known	***If no: possible measures***
Is the employer sensitized? Does he see a problem? Would he like to act?		
Is the proposal for systems design logical? Does a first analysis exists? Are the conclusions plausible?		
Does a main decision to start with a formal project exist? What are the expectations? Who is ordering a project? Does he have the competences?		
Does a clear understanding about the procedure exist? Which are the inputs? Does any requirements / standards to structure the project exist?		

Which are the central questions? Which methods should be adopted?

Central questions	***Chosen procedure (proposed methods & tools)***

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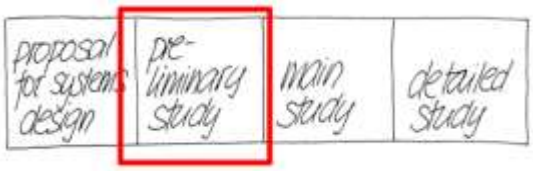

C3: **Are you required to work on a "preliminary study" or part of it? What is missing?**

A «preliminary study» is necessary if there is no principle solution / no general framework about the new solution which hat to be detailed in a main study. See below some questions to be answered:

Questions	***answers***	
	Yes / known	***If no: possible measures***
Does a real need for a new or modified solution exist?		
Do you already know the main problem?		
Did you involve the people who should be involved or who are affected by a new solution?		
Is the scope clear and practicable? Is this also the opinion of the employer?		
Are the requirements defined and accepted by the employer?		
Did you develop enough different options / variants? Do you know different possible solutions?		
Can you evaluate the different options / alternatives?		
Is it possible to make a decision for one of the options?		
Do you know critical elements and assumptions?		
Do you know the links to other projects?		

Which are the central questions? Which methods should be adopted?

Central questions	***Chosen procedure (proposed methods & tools)***

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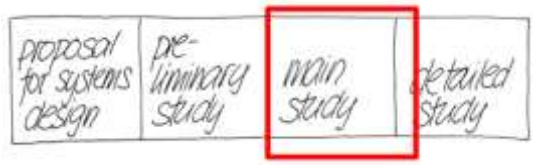

C4: **Are you required to work on a "main study" or part of it? What is missing?**

A «main study» is indicated if there is no concept about the new solution which has to be refined / elaborated on in a detailed study or which has to be realized. See below some questions to be answered:

Questions	***answers***	
	Yes / known	***If no: possible measures***
Have you already made a concretisation from the abstract principle solution to a concrete concept?		
Have you already completed a detailed analysis in reference to the development of a concept?		
Have you already developed alternative options ? Have you already analysed different options?		
Is it possible to make investment decisions based on the information already existing?		
Do you know the critical elements?		
Did you involve people who can be affected by the new solution?		
Is it possible to make a final decision about the concept? Would it be a good solution?		
Are the priorities for further steps clear? Is the basis of the information sufficient?		

Which are the central questions? Which methods should be adopted?

Central questions	***Chosen procedure (proposed methods & tools)***

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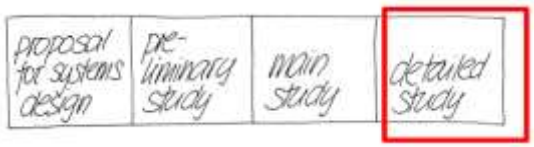

C5: **Is it indicated to work on a "detailed study" or part of it? What is missing?**

A «detailed study» is indicated if there are no detailed concepts about specific parts of the new solution. Following some questions to be answered:

Questions	***answers***	
	Yes / known	***If no: possible measures***
Did you already work on a detailed information basis - with respect to the realization process?		
Do the detailed concepts fulfil the requirements and restrictions of the main concept?		
Is it possible to integrate the detailed concepts into the main concept? Do they fulfil the intended functions?		
Do the detailed concepts have undesired effects?		
Are the detailed concepts designed in the right way that they can be realized easily?		

Which are the central questions? Which methods should be adopted?

Central questions	***Chosen procedure (proposed methods & tools)***

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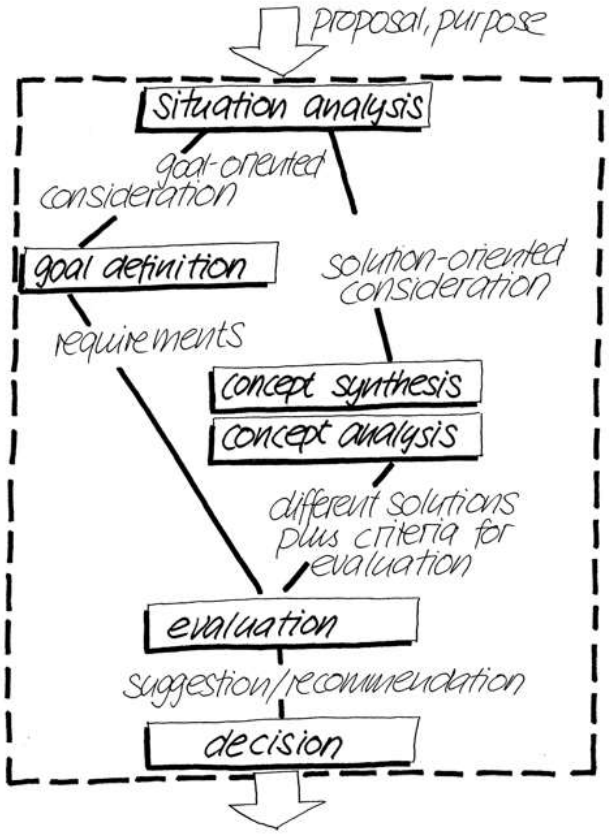
D Problem-solving Cycle:
Smart structuring of a project in reasonable working steps…

The generic problem-solving concept (Problem-Solving-Cycle) is a basic structure for tackling any defined big or small problem in any life cycle phase of a system. It proposes a series of topics, which should be tackled - principally in an iterative manner - within a distinct planning step. The results of the individual planning steps should be coherent.

Structure your procedure in suitable working packages based on the concept of the «Problem-Solving Cycle»!



Situation analysis:
- *task analysis*
- *analysis of the current situation (System and environment)*
- *future-oriented analysis / trend analysis*
- *documentation about the problem / need of actions*

Goal definition:
- *system goals, as well as*
- *project goals*

Search for solutions:
- *options / alternatives (rough synthesis / detailed synthesis)*
- *review – capability (fulfilling of the compulsory goals)*

Evaluation and decision making:
- *transparency about the differences*
- *arguments for and against specific solutions*
- *cost-benefit*
- *…*

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D1: **Situation analysis**…

The situation analysis is the first work step. It includes the investigation of the current situation. The results of the situation analysis are the basis for the goal definition and the search for a solution. In the following some questions:

Questions		***answers***	
		Yes / known	***If no: possible measures***
	Task analysis done? (compare sheet A)		
IST-Zustand	System boundaries defined? *(compare sheet B: B3 and B4)*		
	System and relevant environment analysed?		
	Summary of strengths and weaknesses completed?		
	Cause-effect-analysis completed?		
Zukunftsanalyse	*Trends about the future behaviour of the environment analysed?*		
	Trends about the future behaviour of the system (without any additional intervention) done?		
	Summary of opportunities and threats completed?		
	Cause-effect-analysis completed?		
	Problem / need of actions documented?		

Which are the indented steps within the situation analysis? Which methods and tools should be applied?

Intended steps	***Chosen procedure (proposed methods & tools)***

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D2: **Goal definition**…

The goal definition uses the results of the situation analysis to identify requirements. The search for problem solutions obtains a clear direction only when goals are set and recognised by the planning team. Goals and external conditions guide the concept synthesis and are used as criteria for the later evaluation of alternative solutions. In the following some questions:

Questions	***answer***	
	Yes / known	***If no: indented measures***
List of goals completed? Does the list have «functional goals» as well as "economical goals"?		
Are the goals measurable?		
Is the list of goals accepted by the employer? Does the employer mention the same priorities?		

Which are the indented steps within the situation analysis? Which methods and tools should be applied?

Intended steps	***Chosen procedure (proposed methods & tools)***

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D3: **Concept synthesis and concept analysis**…

In the following some questions:

Questions		***answers***	
		Yes / known	***If no: possible measures***
Concept synthesis	*Have you developed different options / alternative ideas?*		
	Did you apply creativity methods?		
	Did you collect all ideas from people who are involved in or affected by the project?		
	Did you document the arguments why some options have been eliminated?		
Concept analysis	*Have you improved successful options step by step?*		
	Have you checked all compulsory goals?		
	Do you have more than one suitable option?		

Which are the indented steps within the situation analysis? Which methods and tools should be applied?

Intended steps	***Chosen procedure (proposed methods & tools)***

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D4: **Evaluation and decision**…

Concept synthesis and concept analysis build on the results of situation analysis and goal definition. Their purpose is to develop alternative solutions and to test them for suitability and feasibility. In the following some questions:

Questions		***answers***	
		Yes / known	***If no: possible measures***
Evaluation	*Did you evaluate all options?*		
	Is the evaluation documented?		
	Did you document the differences between the options?		
Decision	*Have you involved the employer? Does the employer accept you evaluation / your priorities?*		
	Did you document the consequences of a decision? Have you explained the consequences to the employer?		
	Are the following steps documented? Are these procedures / Is this procedure accepted by the employer?		

Which are the indented steps within the situation analysis? Which methods and tools should be applied?

Intended steps	***Chosen procedure (proposed methods & tools)***

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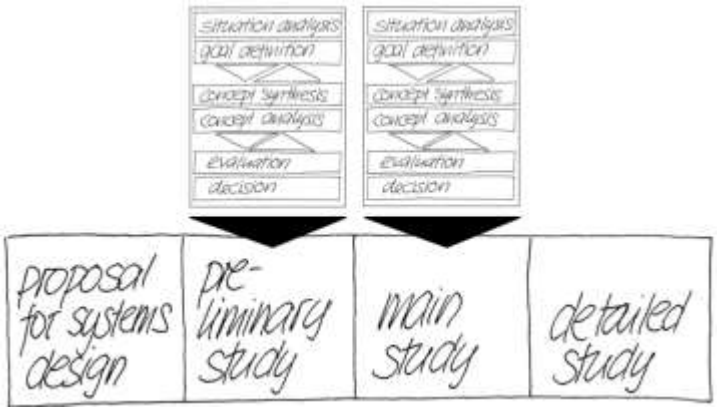
E Interaction between «problem-solving Cycle» and «life-phase Model»:
Plan self-conscious parallel task – be aware of the synchronisation…

Within every life-phase a lot of different jobs have to be done. Therefore, the following question: Is it suitable or necessary that the project team is working parallelly on different tasks? If yes, you can shorten the delivery time. The process will become more complex and you have to balance the tasks continuously.

Which basic model is suitable for your project?

I) One «problem-solving cycle « for every life-phases?
(="simple" application of "Systems Engineering"**?)**

Please document your decision!:



II) Parallel «Problem-solving Cycles" for one or several life-Phases?
(=more complex application of "Systems Engineering")

Please document your decision and answer the following question: How would you like to do the balance / the synchronisation between the parallel "problem-solving Cycles"?

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