Abstract. All too often engineering products are created ‘because we always do so’. Projects phases are introduced without questioning the utility, designs are being detailed without connecting to the decision process, or the preliminary research is badly matching the designers’ needs. So, a big part of the systems engineers role is not only the engineering itself, but matching the engineering process with the project at hand and the goals that must be fulfilled at each design stage. In this paper, we will discuss the tailoring of the typical System Engineering life cycle and project stages onto the life cycle processes of a project at ProRail, the Dutch railway infrastructure provider. ProRail is a major government procurement organization, with revenues of over € 2,000,000,000. Typical projects range from € 100,000 to over € 100,000,000. ProRail has a large legacy system deployed, dating back over 150 years to the first railways in The Netherlands.

Introduction

This paper is focused on the situation at ProRail, the Dutch railway infrastructure provider. ProRail is a procurement company: it does not design or build anything itself, with only a few exceptions. The main source of finance is the public sector, in the form of the national and local governments. Most of the design is being done by engineering companies, either directly hired by ProRail or subcontracted by a building company.

The project environment can be characterized by the following:

- the railway system in The Netherlands consists of nearly 3000 km of tracks, a legacy system which has been evolved mainly over the last fifty years;
- these tracks are being used 24 hours a day, 7 days a week, 365 days a year
- The Netherlands are a densely populated country, with over 16 million people living on about 40,000 square km (15,500 square miles). Almost all of the land area is cultivated.
- The Netherlands have a strong culture of discussion and consensus; there is little chance on just forcing a decision
- the railway system is based on several country and company specific technologies, with few commercial, of-the-shelf elements.
- the complexity of projects depends on the logistics, for a large part, rather than technology

ProRail has, at any given moment, thousands of projects that are being worked on. Each year, the company invests nearly € 600 million in maintenance projects and € 1,000 million in the construction of additional assets.

Maintaining an acceptable quality level of the output requires standardization and common practices. One way to impose standardization is by using decision gates and to require certain documents to be produced at each specific decision moment. When doing so, the organization has to cope with two major questions: 1) what products, i.e. documents, need to be produced at each decision gate and 2) which decision gates should be defined? These questions are mentioned in that order, because the inapplicability of a trial set of products – “we don’t need those in our projects” – lead to the demand for a differentiation in decision ‘life cycles’.

These questions lead to the strong conviction that the use of systems engineering is closely coupled to the architecture of the different process life cycles or design stages within projects. The goal of this paper is to provide a line of thought, an approach for people needing to integrate project processes and other applicable processes with their engineering process.

This paper is in three parts. In part one the main definitions and overall view on tailoring projects will be explained. In part two we will elaborate on the five issues we deem of interest for this definition. In part three we will present, as an example, the core process at ProRail and its tailoring issues.
Part One

Definitions

For a proper understanding of the terms mentioned in this article, we need to address a few commonly used concepts, and define them for the context of this paper.

- **Engineering**: a period within the development stage of the system life cycle. The development stage begins with sufficiently detailed technical refinement of the system requirements and the design solution and transforms these into a detailed design when implemented:
  - that can fulfill the requirements,
  - at a level of detail where risks are mitigated,
  - fit for procurement.

- **Life cycle**:
  - System life cycle: the evolution with time of a system-of-interest from concept to retirement. ProRail has an extensive legacy system, over 150 years old for the eldest parts. More often than not, the system-of-interest needs to be defined from scratch at the start of a project, instead of re-using earlier system definitions. The system life cycle is usually focused on the manipulated objects, rather than the entire system or subsystem.
  - Process life cycle: the evolution of a process from start to finish.
    Within rail projects different project processes can be defined, each with its own process stages. Major project processes within a rail infrastructure project are development, (generic) project process, stakeholder process / decision making process, procurement / contracting process.

- **Phase**: a stage in a process of change or development [www.dictionary.com]

- **Phasing**: to schedule or order so as to be available when or as needed [www.dictionary.com]

- **Process Stage**: a period within a process that relates to major progress, concluded by the achievement of a milestone

- **Project**: an endeavour with defined start and finish dates undertaken to create a product or service in accordance with specified resources and requirements.

- **System Stage**: a period within the life cycle of a system that relates to the state of the system description or the system itself

- **Stage**: a single step or degree in a process; a particular phase, period, position, etc., in a process, development, or series [www.dictionary.com]

- **Stakeholder**: A person or organization who will be affected by (positive or negative) or has the ability to influence a new product or a project

- **Decision making process**: a process to select the most beneficial course of project action where alternatives exist; a significant part of the decision makers in a ProRail-project might not have a financial interest in the project, e.g. people living in the vicinity or environmental organizations can be deeply involved in the decision making process.
Defining and designing engineering process activities and products within the engineering context

Why discuss the engineering process instead of the project process? The engineering life cycle isn’t necessarily the dominant life cycle in a project. It could well be Prince2¹ or any other project management approach. In this paper we want to focus on the engineering life cycle, because that cycle has the closest coupling to the systems engineering processes.

To design the engineering process (i.e., stages, processes, activities, and products) for a specific project, the following major aspects should be considered:

Project type. Multiple engineering and system architecture approaches are being used within organisations to design the system-of-interest. Adaptation to the project type is a necessity. Within ProRail projects can differ from mono-disciplinary replacements to the realization of new railway track/line.

Knowledge of the different process stages. In a project, multiple processes with different lifecycle stages exist: decision making, contracting, and engineering. All of these cycles have their own dynamics and milestones and need to be coupled to be effective and efficient.

Goal oriented engineering stages. The output of each engineering stage is initially not to produce a certain product or document, but the goal that has been reached and that has been captured within the product or document. For instance, it’s not the detailed design one needs, but the design that has enough detail so the risk level is acceptable, the chance that the project result will be satisfying is high enough and the procurement process can be executed. These goals are affected by the different process and project type.

Risk based detailing. Each engineering stage, one has to question: “what risks need to be mitigated in this specific stage?” Check this, several times during the stage. Link the risks to the goals of the design step and identify the key parameters. For instance, to complete the governmental procedures to be allowed to claim required land, the design needs to be detailed enough to identify the geometrical proportions of the system within one meter, as required by Dutch law.

Requirements based detailing. At the end of each engineering stage, the design should be verified. “Does the design meet the requirements?” This seems trivial. The key concept is that the requirements limit the solution space. The design has to fit this solution space.

¹ For more information: www.prince2.com
At the start of a project, the systems engineer will have to work out the systems engineering management plan in which engineering stages are linked with the other process stages. The applicable engineering processes need to be tailored to the project. There is a need for tailored process architecture per project or per type of project, using organizational, national and international standards.

The primary choices that need to be made for architecting the engineering process:
- Develop an engineering model: what milestones and baselines are needed, based on the other applicable processes; nor too few neither too many
  Engineering has an interface with a variety of processes; political decision making, financial constraints and procurement or contracting processes. Hence:
  - decide what procurement strategy will be followed and what the consequences are for the engineering phases and goals;
  - decide what decisions need to be made in order to successfully manage the stakeholders needs and, again, what the consequences are for the engineering phases and goals;
- Identify for each milestone the decisions that have to be made, the starting conditions and what information is needed to make them
- Identify the level of detail required for the engineering activities and products for each element/discipline by the former

Checking risk level and requirements level are defined as two different aspects, where one could argue that this could be combined. The approach used in this paper and the distinction between the two can be characterized as follows:

![Risk and Requirements Diagram]

The Y-axis represents the level in which requirements are met; the X-axis represents the risk level of the design base line being assessed. Ideally, a design can only be deemed correct if it’s in the upper left quadrant.
Part Two

Project type

As proper engineers do, ProRail has tried to categorize projects based on parameters in each project, like complexity, the disciplines involved and the customer. This categorization follows organizational structures and the stakeholder environment in which ProRail operates, but does not necessarily match the categorization from an engineering point of view.

For engineering purposes, the main drive is to optimize the generic processes so that the main focus can be on those issues that make a project unique and not rework the same issues again for each project. Hence, projects are categorized on a basis of likeliness in terms of complexity, disciplines involved, duration, and financial size.

<table>
<thead>
<tr>
<th>Type</th>
<th>Complexity</th>
<th>Disciplines involved</th>
<th>Time to completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>New tracks</td>
<td>Large</td>
<td>Many</td>
<td>&gt; 5 years</td>
</tr>
<tr>
<td>Changes</td>
<td>Medium</td>
<td>Many</td>
<td>2-5 years</td>
</tr>
<tr>
<td>Renewal, replacement</td>
<td>Small</td>
<td>Few</td>
<td>1-2 years</td>
</tr>
<tr>
<td>Overpass, underpass</td>
<td>Small</td>
<td>Few</td>
<td>2-5 years</td>
</tr>
<tr>
<td>Stations and transfer</td>
<td>Large</td>
<td>Many</td>
<td>2-5 years</td>
</tr>
<tr>
<td>Product development</td>
<td>Middle</td>
<td>Few</td>
<td>1-2 years</td>
</tr>
</tbody>
</table>

Table 1 – Examples of the differences between project types

For each type of project, templates are developed for several products, with generic requirements or procedures and stages. This means that several project life cycles can be defined.

Complexity. If a project gets more complex, there is more need for breaking down a project in several stages. Hence, a typical project life cycle of a complex project consists of more stages than a simple one.

Disciplines involved. Engineering disciplines in a legacy system environment have a high degree of evolutionary design. This means that over the years each specific discipline has developed its own engineering cycle with its own stage.
Time to completion. As with complexity, a project with a longer timeline has a need for more stages, usually. This means that the need for baselines and decision gates depends on this timeline.

Discerning applicable processes
After establishing the applicable type of project, four main types of project processes can be defined within a project, each with its own process stages.

(Generic) project process. Generic project management processes from initiation, managing to commissioning a project. Different stages exist, depending on which project management method is applied, like Prince2. Within these stages specific stages should be defined, which are influenced by the following processes.

Stakeholder process / decision making process. The project needs to generate information for the decision making process for the principal or client. The main principal for railroad infrastructure is the Ministry of Transportation or a local government. They have a formal and administrative decision making process with different stages. Each stages needs different information.

Procurement / contracting process. ProRail selects contractors to conduct different system life cycle stages. Different types of contracts are used from only design, only realization to integrated design and construct contract. Processes are conducted for choosing the right contracting procedure, organization form and contract work breakdown, selection of a contractor and the contract management approach. The type of contract has impact on the information needed from the engineering process by the tendering company during this phase.

Engineering process. The engineering process translates the requirements into a detailed design, when implemented, which can fulfill the requirements. Depending on the needed engineering disciplines and context different engineering stages exist. Adjustments in the safety related electronic systems for signalling should follow the EN 50126/50129 stages. In the dutch civil engineering a general engineering life cycle is agreed upon by engineers, construction companies and principals2.

The example we present in Part Three of this paper – the ProRail Core Process – is an example of a combination of two processes: it combines the decision-making process with the overall project process.

To further clarify the processes mentioned above, we will elaborate on two of these processes.

Procurement and contracting strategies
Concerning contracting policy, ProRail operates on three lines of approach:
1. the most efficient organizational context in which ProRail plans future operations
2. how the identified operations can be allocated to one or more contracts, so that the best cost-performance ratio is realized, and in what form the identified contracts should then be allowed to assume;

2 RVOI/DNR; General terms and conditions for consulting engineers in The Netherlands
3. the most rational form of tender, given the specific case\textsuperscript{3}.

![Figure 3 - Contract types](https://www.prorail.nl/Zakenpartners/Aanbesteden%20en%20inkoop/Documents/ACB00101-v001%20Contracting%20Policy%20of%20ProRail.pdf)

Depending on the contract strategy that is chosen, the contracting or procurement phases can differ on three axes:

**Legal procurement procedure.** As prescribed by European and National Law and as applied in ProRail policies.

**Organizational form.** As agreed upon with the contractors, defining the allocation of the total amount of work to the parties involved.

**Negotiation strategy / tender procedure.** There are several options, ranging from just written communication in response to an anonymous Request for Proposal to an elaborate competition with co-engineering by all tendering parties.

The stages within the procurement or contracting process are Publication – Request for Proposal – Tender – Contract Management. These stages are the same for all the types of contracts but the starting conditions are different. For example:

- For a Design & Construct contract the starting conditions are:
  - Concept contract ready: with requirement specifications and preliminary design from the engineering
  - Public building permit obtained: esthetic design and conditions must be agreed
  - Defrayment obtained by an agreement with the financial party

- For a Construct contract the starting conditions are:
  - Concept contract ready: with detailed design and specifications form the engineering
  - All conditioning ready: detailed design needed for public permits
  - Warrant obtained from the party providing the funding.

Hence the type of contract has impact on the detail level of the engineering which is needed as input for the contract, but has also impact on the level of detail which is needed as input for the public permits.

\textsuperscript{3} [http://www.prorail.nl/Zakenpartners/Aanbesteden%20en%20inkoop/Documents/ACB00101-v001%20Contracting%20Policy%20of%20ProRail.pdf](http://www.prorail.nl/Zakenpartners/Aanbesteden%20en%20inkoop/Documents/ACB00101-v001%20Contracting%20Policy%20of%20ProRail.pdf)
**Stakeholder process**

Because governments always have something to say in plans when building or replacing railway infrastructure, a project will always need to incorporate the acquisition of public permission in its plans.

Depending on the complexity and size of a project, processes can be defined at three levels:

**National or regional level.** Control of land use is regulated in extensive procedures in The Netherlands. Procedures can take from one to three years, but even longer if there’s a lot of resistance from the stakeholders.

**Regional or local level.** Land use is controlled by zoning plans, which describe the allowed current and future use of the land. The provinces authorize zoning plans, the local government makes new plans and decides whether or a new project will fit in the existing plan.

**Local or individual level.** At a local level, only the local government authorizes the construction of or changes to infrastructure and buildings, by means of permits, e.g. a building permit.

In the following table the required procedures (external decision making process) for both a complex and simple project are mentioned.

<table>
<thead>
<tr>
<th></th>
<th>Complex project</th>
<th>Simple project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land acquisition</td>
<td><em>Tracéwet</em> procedure</td>
<td>Acquisition or Expropriation</td>
</tr>
<tr>
<td></td>
<td>- Acquisition or Expropriation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- System level design for geometry 1:1000 + 1m</td>
<td></td>
</tr>
<tr>
<td>Designated land use</td>
<td><em>Tracéwet</em> procedure</td>
<td>Change zoning plan</td>
</tr>
<tr>
<td></td>
<td>- System level design for functionality</td>
<td></td>
</tr>
<tr>
<td>Environmental issues</td>
<td><em>MER</em></td>
<td><em>WION</em></td>
</tr>
<tr>
<td></td>
<td>- Noise level forecast</td>
<td>- All permits needed from an environmental point of view, like flora &amp; fauna, archeology, existing pollution of ground and water, existing objects</td>
</tr>
<tr>
<td></td>
<td>- Pollution level forecast</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- + all steps from simple project</td>
<td></td>
</tr>
<tr>
<td>Building permit</td>
<td>Detailing of earlier plan, already with the commitment from stakeholders</td>
<td>Single request for new permit</td>
</tr>
<tr>
<td></td>
<td>+ all steps from simple project</td>
<td>- Documents needed to get architectural consent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Documents need to verify constructional integrity</td>
</tr>
</tbody>
</table>

Table 2 – Common cycles for public permits

---

4 Procedure from Dutch national land use legislation and financial discion making, top-level
5 Environmental Effects Study
6 Dutch land use law, local level, concerning all applicable permits described.
For a complex project such as a new rail tracks the *Tracéwet* and *MER* procedure are leading in the decision making process. This gives the following cycle with stages:

![Diagram](image)

**Goal Oriented Engineering Stages**

For the purpose of this paper, an engineering process is divided into two phases: the 1) concept phase, in which the problem space (e.g. Wasson, 2005) is defined and the 2) development stage, in which the solution space is defined and the design is being detailed, verified and validated.

The development (design) of the system-of-interest is developed from coarse to fine. The input and output are clear when looking at the entire engineering process: from vague customer demands to a well defined solution space (reference) at a level of detail that the risks are mitigated, fit for procurement (for projects from ProRail).

Defining engineering stages (development sub stages) within the development stage depends on:
- Stages and needed output for other processes
- Needed engineering disciplines

**Stages and output for other applicable processes**

When defining the engineering stages, the other types of stages are taken into account. The engineering stages need to be adapted to meet the engineering needs from these other stages.

![Diagram](image)
In all of the stages within these cycles, the level of detail and the products required are defined by the processes that need input from the engineering process: contracting and stakeholder/decision making process.

**Needed engineering disciplines**

In multidisciplinary projects different disciplines are involved. Each discipline has its own engineering cycle with its own stages. For example, within a multidisciplinary railway line project two different engineering stages exist:

<table>
<thead>
<tr>
<th>Civil Engineering</th>
<th>Railway Safety (EN 50126)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• System Definition</td>
<td>• Concept</td>
</tr>
<tr>
<td>• Alternatives</td>
<td>• System Definition</td>
</tr>
<tr>
<td>• Conceptual Design</td>
<td>• Risk analysis</td>
</tr>
<tr>
<td>• Detail design</td>
<td>• System requirements - Apportionment</td>
</tr>
<tr>
<td></td>
<td>• System Requirements - Design</td>
</tr>
</tbody>
</table>

These stages must be mapped to the overall engineering stages related to the other processes.

**Mapping processes within the stages and goals**

When considering the needed output for each stage the technical (engineering) processes (Systems Engineering Handbook, 2006) can be mapped. This is in the further elaborated

**Concept stage.** The main process activity is the collection of stakeholder requirements. Activities within this process are the stakeholder analysis, context analysis, definition of use cases etc.

**Development stage.** Within the development phase or cycle the following processes can be defined:
- Stakeholder Requirements Definition Process
- Requirements Analysis Process
- Architectural Design Process
- Verification Process
- Validation Process

Within each engineering stage (development sub stage) the same processes are repeated.

For example, in infrastructural projects different stakeholders are involved at different development stages, as shown below. This means that stakeholder requirements will be defined at different development stages.
Mapping engineering detail with stages and goals

At the begin of an engineering stage the goals must be related to the system elements and needed engineering output for each element. A goal oriented engineering output (as is input for another process) for a stage has a differentiated level of detail – a serrated edge – for the different system elements. On the one hand specific system elements are completely designed to fulfill the stage goal. On the other hand specific system elements are not designed, only the requirements are base lined. For every element roughly three levels can be distinguished: 1) requirements are base lined – 2) functional architecture/conceptual design (working and coarse form is base lined) – 3) detailed design (form is accurately base lined).

Example of relating goals and needed engineering output are the following:
A goal in an early engineering stage is to define and base line the acquired land, as input for the national land use legislation procedure. Only the system elements that have impact on land use must be engineered:

The first step is an analysis of the goals related to the system break down structure. In the following tables this is roughly elaborated with a part of the railway system break down for the goals baseline acquired land and a cost accuracy of 30%.

<table>
<thead>
<tr>
<th>System/ system element</th>
<th>Energie supply system</th>
<th>Support system</th>
<th>Crossing system</th>
<th>Track system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail related to acquired land</td>
<td>Overhead lines</td>
<td>Electrical substation</td>
<td>Control system</td>
<td>Ground work</td>
</tr>
<tr>
<td>Key Requirements</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Conceptual Design</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Detailed design</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 3 – Engineering detail related to base lining the acquired land
The next step is a detailed description of the design activities. This is not elaborated, but some examples are given in the next section.

### Risk Based Detailing

A derivative of the goal driven engineering is that both the decision making process and the engineering should focus on the managing risks related to the goals. For each stage, the risk level should be defined related to the stage goal, for example, items such as land use, permits, costs, feasibility, fitness for purpose, etcetera. Those risks are migrated by further engineering.

Risk management methods may focus on process related risks, like timeliness, budget overruns or levels of pollution. These are structured and explicitly defined. Technical risks are often implicit in design choices and guidelines discounted.

A way to explicitly define risk levels is the use of structured qualitative risk analysis, along the lines of Failure Mode Effect and Causality Analysis (FMECA) or the use of Fault Tree Analysis.

A goal in the early engineering stage is to define and base line the acquired land, as input for the national land use legislation procedure. Only the system elements that have impact on land use must be engineered. Risks related to this goal are:
<table>
<thead>
<tr>
<th>Risk</th>
<th>Causes</th>
<th>Critical system element</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non compliance</td>
<td>underlying causes</td>
<td>Overpass X</td>
<td>Check the required profile that needs to be free of permanent objects in relation the projected and requested functionality. Use quick ’n dirty calculations to verify the claim of the added construction height being needed.</td>
</tr>
<tr>
<td>System does not meet geometrical constraints: more land needed then is acquired</td>
<td>Construction height of the overpass is higher than calculated, which in turn means that the railway tracks need more vertical adjustment, which makes that the embankment of the overpass requires more space</td>
<td>Overpass X</td>
<td>Check the required profile that needs to be free of permanent objects in relation the projected and requested functionality. Use quick ’n dirty calculations to verify the claim of the added construction height being needed.</td>
</tr>
<tr>
<td>System does not meet geometrical constraints: more land needed then is acquired</td>
<td>No account of the required space of a noise barrier</td>
<td>Noise barrier Y</td>
<td>Detailed sound search to be sure of the exact location en lengt of a noise barrier</td>
</tr>
<tr>
<td>System does not meet geometrical constraints: more land needed then is acquired</td>
<td>No account of the required space for safety path along te rail track</td>
<td>‘Service path’</td>
<td>Safety analysis And conformation from safety authority of use of path</td>
</tr>
</tbody>
</table>

Table 5 – Examples of risks and mitigation

A goal in the early engineering stage is to analyze the environmental effects of alternative rail tracks, as input for discion making procedure. Only the system elements that have environmental impact must be engineered. Risks related to this goal are:

<table>
<thead>
<tr>
<th>Risk</th>
<th>Causes</th>
<th>Critical system element</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unacceptable disturbance of surroundings</td>
<td>Tunnel influences ground water flow and heightens ground water level too much</td>
<td>Tunnel Y</td>
<td>Research ground water flow, calculate impact</td>
</tr>
<tr>
<td>Unacceptable disturbance of surroundings</td>
<td>Rail track with tunnel nearby houses Use tunnel gives unacceptable ‘resonation’</td>
<td>Tunnel Y</td>
<td>Resonation research to invest impact</td>
</tr>
</tbody>
</table>

Table 4 – Examples of risks and mitigation
**Requirements Based Detailing**

At the end of each engineering stage all requirements must be verified. A system should be designed to a level of detail at which it is possible to prove it will meet the requirements. But the verification level differentiate between the requirements and between the stages. This means the level of detail is also defined by the requirements. More specifically, this level is defined by the key requirements that will define the functionality of the system.

Therefore it’s relevant to define both the stage in which requirements will be verified and the verification level. In early stages the focus is on verifying that the requirements from the primary stakeholders (government, internal/external principal) will be met, for example travel time decrease. Later on the focus shifts to verifying that all RAMS aspects can be met.

The verification is needed to be able to draw the conclusion that a specific design fits the solution space as defined by the requirements. It is relevant to acknowledge the fact that some requirements demand detailed engineering in an early stage of the project. Therefore, the preliminary design is not strictly correlated to a standard level of detail for every project. The level of detail follows the requirements.

For example, in the preliminary design stages the following verification levels can be distinguished (not exhaustive):

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow up time x</td>
<td>Detailed: with calculations</td>
</tr>
<tr>
<td>Travel time decrease y</td>
<td>Detailed Calculation y</td>
</tr>
<tr>
<td>Emmission levels</td>
<td>Detailed: calculations x</td>
</tr>
<tr>
<td>RAMS requirements</td>
<td>Coarse: reference</td>
</tr>
<tr>
<td>Constructional reliability</td>
<td>Coarse: expert judgement</td>
</tr>
</tbody>
</table>

*Table 6 – Different verification levels at different engineering stages*

In the detailed design stages the following verification levels can for example be distinguished:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow up time x</td>
<td>No further calculations</td>
</tr>
<tr>
<td>Travel time decrease y</td>
<td>No further calculations</td>
</tr>
<tr>
<td>Emmission levels</td>
<td>No further calculations</td>
</tr>
<tr>
<td>RAMS requirements</td>
<td>Detailed: RAMS analyses (FMECA/FTA)</td>
</tr>
<tr>
<td>Constructional reliability</td>
<td>Detailed: construction calculations</td>
</tr>
</tbody>
</table>

*Table 7 – Different verification levels at different engineering stages*
Part Three

Example: ProRail Core Process

As an example of the complexity of integrating different processes and their respective apportionment, we would like to discuss a process developed by ProRail in 2010. This so-called ‘Core Process’ seeks to integrate over fifty processes that were defined in an earlier stage. These processes were developed halfway the last decade within the Project Department of the company.

Figure 6 - Organizational Structure of ProRail B.V. (in Dutch), available at www.prorail.nl

Realizing projects is one of the company’s core activities. ProRail does so in a professional way. This method has been incorporated in the “Core Process”. In this process, all documents are defined that need to be available at a specific decision gate. This way, every employee knows how his or her individual effort amounts to the overall result. Within the company, one language is used, and projects and customer relations remain manageable.

The Core Process consists of four stages:

1. Concept
2. Alternatives
3. Preliminary Design
4. Realization

1. Concept: A successful project needs a good start.
2. Alternatives: Explore all possibilities to be able to pick the best.
3. Preliminary Design: Choose between further options and prepare for realization
4. Realization: The actual build, culminating in an end product.

Per stage, decision gates are defined. For each decision gate, products are defined. The names of these products and process steps have been agreed upon, for the purpose of clarity in communication.
The core process, the defined names and the definition of processes should lead to a more effective cooperation, and more transparency in investment management.

With this process, ProRail hopes to achieve the following goals:

- Execute projects in a reliable and controlled way
- Work uniformly and structured
- Make work more understandable and easier for employees
- More control over the project portfolio (1800+ per year)
- Serve as a basis for continuous improvement

This effort resulted in the following overview of products, decision gates and life cycle stages.

![Figure 7 - Overview of products per stage in the ProRail Core Process (in Dutch) (limited legibility is intentional)](image)

The y-axis describes different areas for which processes are defined. The x-axis depicts the main project stages, with the ‘traffic lights’ representing the decision gates. All bullets in the matrix define a specific end product in each of the processes, needed as input for the respective decision gate.

This is an example of product oriented phasing; it’s not clear from this figure what the relation between the goal per decision gate and the products is. According to our model, the goals per decision gate must be made explicit on the x-axis.

The elements on the y-axis should contain all relevant defined processes, only processes, not departments or products. Next, the apportionment of the different processes, the stages and their respective output should be mapped on the decision gates of the overall project process. Basis for this mapping should be the consideration of the contribution of a process output to
the goal of the respective phase: “Do I need this to make a decision?” Further honing of the model would include risk and requirement based definition of the detailing of each product needed to reach the next decision gate.

Conclusion and recommendations

Crucial for an effective engineering process is an understanding of the specific goals per engineering stage. The system engineer needs insight in the discernible processes to which the engineering process delivers its input and the chosen project stages.

Architecture of the engineering process consists of defining the general stages in the project, allocating the specific technical process in these stages and mapping the needed level of detail. Tailoring of the stages is needed, the processes are standard. The next step is to apply the standard stages to an individual project and tailor these stages after defining the specific project needs. Engineering stages and technical processes are then defined and frozen in the Systems Engineering Management Plan.

Goal oriented architecture of the engineering stages will lead to risk and requirement driven detailing. It’s important to review these tailoring decisions at the beginning of each engineering stage, and to further detail and develop the engineering stages on the fields of risks, feasibility, compliance and results. This review consists of:

- Identifying the goals for the upcoming engineering stage. Couple the different processes in the project.
- Treat each of the sub goals as a separate aspect, and analyse the critical objectives that need engineering input.
- Execute a risk analysis from a technical point of view and identify the items that need further detailing.
- Reiterate on these steps after completing the engineering products to check whether all objectives are reached and all needs for engineering products are met.

Using goal oriented engineering stages will help a systems engineer or systems architect to integrate a multitude of relevant processes with his or her engineering process, to eventually rise above the product and production level point of view to a service level point of view based on the goals of each process.

References

To write this paper, we used the following literature: “Tailoring Systems Engineering Lifecycle Processes to meet the challenges of Project and Programme applications”, by Richard Adcock, ISO 15288, the INCOSE Handbook, the DoD website on SEMP, the EN 50126, www.prorail.nl, “System Analysis, Design and Development”, by Charles E. Wasson.
Biographies

Richard Bosch (1976) is a Rail Systems Engineer at ProRail, the Dutch railway infrastructure provider. Richard obtained his M.Sc. in Civil Engineering en Management at University Twente. From 2000-2009 he worked for Ministry of Infrastructure. He was a project engineer for several major railroad projects. He contributed to the tailoring and implementation of SE processes in the Ministry of Infrastructure by developing best practices and standards, workshops, coaching project teams and reviewing projects. In 2009 he became Rail Systems Engineer at ProRail and is involved by the development of several road bridges, underpasses and overpasses. He also developed several SE standaards

Paul Brouwer (1975) is a Manager at the Rail Systems Engineering department at ProRail, the Dutch railway infrastructure provider. Paul obtained his M.Sc. in Systems Engineering, Policy Analysis and Management at Delft Technical University. As a consultant, he worked for several major infrastructural projects, tailoring the SE processes to the Dutch construction industry. Projects involved were among others the reconstruction of several major highways and HSL South. In 2005 Paul was employed by ProRail. There, he procurement manager in for a multitude of projects, ranging from the construction of new train stations to the expansion from two to four tracks of several railway corridors, from €100,000 to €100,000,000 and more. Within his company Paul co-developed several SE courses and trains co-workers in the use of SE.

Paul has been a member of the board of INCOSE Netherlands from 2002 to 2006, as Treasurer and as President. He was involved in the organisation of the IS2008 (Treasurer of the host committee) and is a member of the ITTS Working Group.