Developing a framework for the conceptual design of automated freight transportation systems
Systems Engineering Design & Models

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There is an increasing interest for new automated freight transportation concepts. With increasing transport demands, problems arise in the transportation and distribution of freight. Expansion and improvement of existing systems is not always possible and does not always lead to efficiency improvements or better living environments. Society is demanding efficient sustainable transportation systems for the future.

Although there is a desire to develop new concepts for automated freight transportation systems, there is no design approach or methodology available for the conceptual design of automated freight transportation systems. The goal of my research is to develop such a design approach. This paper focuses on developing a basic framework for this approach.

In order to develop a basic framework for the conceptual design of automated freight transportation systems, a literature survey on design methodology was performed. Focussing on automated freight transportation systems, two interesting disciplines were distinguished: Systems Engineering (SE) and Engineering Design (ED). Both are discussed in this paper. This research developed a basic well-founded framework for conceptual design. Further research will focus on further detailing and development of this generic framework to make it useful for the conceptual design of automated freight transportation systems.

**Keywords**

freight transportation systems, design methodology, systems engineering, engineering design
2 Characteristics of Automated freight transportation systems

Automated freight transportation systems typically are complex systems with many interacting elements and many parties and disciplines involved. Characteristic is the variety of technologies connected together. Civil engineering, mechanical engineering, electrical engineering, data communication, software/hardware engineering, labour organisation and user interfaces are only a few of the fields of expertise involved in larger automated freight transportation systems.

Although there are some inspiring operational examples to be found, automated freight transportation is still in its early development stage. Automated freight transportation systems are often newly developed systems, with new components and/or new methods for control.

Freight transportation systems in general have a long life cycle, require large investments and can have a great impact on the environment. This makes it even more important to pay attention to the design and development of the system.

This research focuses on the conceptual design of automated freight transportation systems, and takes an engineering point of view. Although other fields are also important to develop and operate a transport system, such as economics, business or law, engineering is leading when considering the actual designing of a system.

When focusing on the design (or engineering) of automated freight transportation systems, two interesting fields of study can be distinguished in literature: Systems Engineering (SE) and Engineering Design (ED). Evolving from the ballistic missile programs in the mid 1950's in the USA, Systems Engineering discusses the development and engineering of complex systems, often taking a broader perspective considering the whole life cycle of a system. Engineering Design focuses more on the actual design process of new (technical) products. The first ED models were developed mainly by German engineers in the 1960's. Both, SE and ED models are discussed in this paper.
Systems Engineering (SE) discusses the engineering of complex systems. SE began to evolve during the late 1950's. With the "race to space" and the development of nuclear missiles, there was a need for a more systematic approach. Parallel to the space and defense sector, SE also evolved in the commercial sector. An early publication by [Hall, 1962] presents the development of SE within telecommunications industry. A comprehensive overview from academia is presented by Andrew Sage, with many publications and books on SE (a recent publication [Sage et al 2000]). The International Council on Systems Engineering (INCOSE) has developed a more practical "how to" guide for SE. This chapter presents some of the most important models of the SE process found in literature.

3.1 Phases, steps & matrixes

The structuring of the SE process using phases and steps can be traced back to [Hall 1962]. Phases provide the main structure of the process in the time dimension, while steps (or elements of the fine structure [Hall, 1962]) are exercised in every phase. The Systems Engineering Activity Matrix introduced by Hall is presented in Figure 3-1. The phases are presented vertically and the steps horizontally, every box representing an activity. The phases again show the time sequence of activities (covering the whole life cycle of a system), while the steps show the logical sequence of activities to be taken in every phase.

![Figure 3-1: Activity Matrix [Hall 1989]](image)

Apart from this 2D matrix, Hall also developed a 3D matrix including the different professions required to develop a system. This matrix is presented in Figure 3-2.
Figure 3-2: 3D Matrix by Hall

The activity matrix using phases and steps provides a plain and simple visualisation of the SE process and is therefore useful for structuring a complex design project. However, the model does not show the iterative character of the design process (as already recognised by its authors), nor does it allow for any other relation to be integrated, as this would rapidly obscure the model. The activity matrix is therefore a good model for the overall global structuring of the design process, but less appropriate as a "working model" (It does not reflect the actual design process). An often-heard comment on models of the design process is that they don’t include people. The 3D matrix presented by Hall clearly presents professions (type of people), making it possible for a person to position oneself within the project. It also emphasizes the many different disciplines necessary to develop a complex system. However, similar to the activity matrix, it does not represent the actual design process.

3.2 Spiral models

Although the activity matrix clearly structures the SE process, it tends to hide other typical aspects of the design process as already discussed above. To better emphasize the iteration and convergence of the design process, a spiral model was also used.
connection are added, permitting any element to follow any other element in any possible sequence. The same logical steps repeated for every phase are presented on the outside of the spiral.

Figure 3-3: Spiral model by [Hall 1989]

A different spiral model for software development is presented by [Boehm 1988] (Figure 3-4). Here the emphasis was on visualising the increase in cost instead of the convergence. A software development process is presented, starting in the centre and spiralling outwards. The length of the radius measures the cost of the project, the four quadrants representing the steps, and each cycle being a phase in the process. (to enhance legibility, some artistic license has been taken with the increasing cumulative cost dimension). This model stresses a risk drive approach, making use of a prototype to resolve the risks in every phase. On each cycle, sufficient risks are to be removed in order to proceed to the next cycle.

Although the spiral models permit a better visualisation of certain aspects like convergence or cost increase of the design process, they are more complex to use. Spiral models can be helpful to stress a certain aspect, such as iteration, convergence or cost increase, but are perhaps too complex for the overall structuring of a design process.
3.3 Waterfall models

The term "waterfall model" was introduced by [Royce 1970]. He developed the model presented in Figure 3-5 (left) for developing software. Since then, many other waterfall models have been developed. [Sage et al. 2000] for instance, present a waterfall model containing seven phases with feedback loops as shown in Figure 3-5 (right).
iteration can be introduced using the feedback loops, the waterfall model primarily suggests an ongoing motion (down the waterfall). Waterfall models are therefore less appropriate for representing the design process of complex new systems, where there is a greater likelihood of significant iterations.

3.4 V-process model

The V process model presents the phases in a V shape emphasising the decomposition sequence of the first half towards a lower and more detailed level followed by the integration sequence of the later half. A V process model by [Sage, 1995] is presented in Figure 3-6. The different horizontal levels indicate different levels of detail requiring different perspectives.

The phases used by Sage in the V model are similar to those presented in the waterfall model but adapted to software design. Sage indicates three different perspectives, being that of customers (top level), system architects (mid level) and programmers (bottom level) and characterises these perspectives as being dominantly purposeful, structural and functional.

![Figure 3-6: V process model for software design by [Sage 1995]](image)

Although the V process model has the same advantages and disadvantages as the waterfall model, the horizontal relations present an interesting extra relation between the otherwise sequential phases. For the conceptual design phase a relation is drawn with the integration and test phase, indicating that a similar perspective is required for both phases. This suggests an interrelation between two otherwise separated phases in time, both needing the same (kind of) people. The model also shows that during the design process, different perspectives (and thus people) are needed.
3.5 Models by Department of Defense USA & INCOSE

Two authorities on Systems Engineering are the Department of Defense USA (DoD) and the International Council On Systems Engineering (INCOSE). The DoD has developed and applied SE for many decades, which makes their experience very valuable. INCOSE is a younger organisation founded in 1990 with members from many different fields providing a broad common platform for Systems Engineering. Both organisations have developed a model of the Systems Engineering process.

The systems engineering process developed by the DoD is shown in Figure 3-7 [DoD 2001]. The process input consists primarily of consumer needs, objectives, requirements and project constraints. Three fundamental steps are defined; Requirements Analysis, Functional Analysis/Allocation and Synthesis. Also, three feedback loops are used: Requirements Loop, Design Loop and Verification. A fourth separate element within the model is System Analysis and Control. The activities within this element apply to all steps in the systems engineering process as indicated by the double arrows in the model. The Process output depends on the level of development, but in general is any data that describes the product configuration or the process, necessary to develop that product.

Figure 3-7: Systems Engineering process by [DoD 2001]

INCOSE publishes a systems engineering handbook as a practical "How To" guide for all engineers [INCOSE 1998]. A model of the SE process developed by INCOSE is presented in Figure 3-8. They state that SE is basically an iterative process starting at the top level (system level) and propagating downward through a series of steps.
Figure 3-8: Systems Engineering process by [INCOSE 1998]

The figure suggests a circular motion with six steps and different levels (or layers). At first sight, this representation of the Systems Engineering process is perhaps comparable with the spiral models discussed earlier (Circular steps with the layers being the phases). However, the number of levels per step are not the same for each step, nor are the indications per level consistent, as would have to be the case for phases.

Although the model is perhaps less "fundamentally correct" when compared to previous models, steps and phases can still be distinguished. Furthermore, the expressions used in the INCOSE model can be considered more general and modern. The basic steps that can be distinguished are: Analysis & Definition, Design, Production, Delivery and Tradeoffs. Although the phases are not all clearly represented in the model, some can be recognised, e.g. Conceptual-Preliminary-Detailed design, Production & Delivery-Installation-Operation-Disposal. A better representation of phases is presented in Figure 3-9. This figure shows a comparison of program phases for five different organisations.
Figure 3-9: Comparison of project phases [INCOSE 1998]

This comparison emphasizes that all programs are fundamentally similar in that they move from the project initiation phase through the system concept phase, further development phase, production phase, operational phase etc. (see bottom time line). Milestones (typical control gates in figure 3-9) separate the phases. A typical control gate is that of system concept approval, after the initiation approval and before the development approval. Generally the conceptual design phase (the focus of this study) is placed after the initiation phase and before the detailed design phase (further development).
Engineering Design (ED) focuses more on the actual design process. ED models have been developed since the early 1960's. The first models were developed mainly by German engineers. The models developed by [VDI2222 1977] and [Pahl & Beitz 1999] are perhaps the best known models of the design process worldwide. Other interesting models have been developed by [Cross 1992] and [Roozenburg & Eekels 1998]. These four models of the ED process are presented in this chapter.

4.1 VDI

The general approach towards design according to the “Verein Deutscher Ingenieure”(VDI) is presented in Figure 4.1 This model presents the engineering design process as a sequence of seven stages, correspondingly producing seven results. The stages are often combined into design phases, the names and numbers depending on the project or field of application. Phases often used are: Clarification of the task (I), conceptual design (II), embodiment design (III) and detailed design (IV).

![Diagram of VDI model for the Engineering Design process](image)

**Figure 4-1: VDI model for the Engineering Design process [VDI 2221 1986]**
This VDI model does not distinguish between phases and steps as clearly as the models presented in the Systems Engineering section. The VDI model emphasizes the time dimension (with phases), not clearly presenting the logical steps that take place in every phase. This could be the reason why this logical dimension is sometimes overlooked, "...not so much by its authors but by its users and above all, its critics..." [Cross & Roozenburg 1992]. Although the steps are not clearly shown, they are discussed by the authors. They emphasize that the seven stages can be further subdivided into additional steps, depending on the complexity of the task. The stages introduced by the VDI are however not the same as phases. Certain stages in the model even more resemble steps. One could state that although phases and steps are mentioned and described by the VDI, they are not clearly represented in the model. The terms used for the stages are furthermore not clearly distinguishable as phases nor as steps. The stages defined by the VDI are perhaps more a combination or mixture of phases and steps.

Stages however, do structure the design process by specifying intermediate results, thereby helping the designer to be more effective and efficient. The authors further note that the stages do not necessarily follow rigidly one after the other. They are often carried out iteratively, returning to preceding ones, thus achieving a step-by-step optimisation.

The VDI furthermore suggest subdividing a complex overall problem into sub-problems. This makes it easier to find a solution, but also makes it possible to break down the problem solving process into parallel paths. This structuring of the problem is shown in Figure 4-2. The overall problem is divided into sub-problems for which sub-solutions are found which are then combined into an overall solution (reading from top to bottom). The figure, however, also illustrates the fundamental systematic approach of structuring of a system into sub-systems and system elements (starting at the bottom going up). Such a structuring of the problem and system promotes working in a systematical way, the development of alternative solutions, the adoption of known and well-tried sub-solutions, and a rationally organised division of labour.

![Figure 4-2: Structuring the problem and system](image-url)
all solution variants in all phases, would lead to an explosion of the number of possibilities to be studied. On the other hand, restricting oneself to one track only within the network of possibilities is dangerous because then the better or best alternatives may be overlooked. One is therefore urged to diverge and converge in each phase. This important methodical principle is visualised in Figure 4-3.

Figure 4-3: Divergence and convergence

4.2 Pahl & Beitz

The design process according to Pahl & Beitz is presented in Figure 4-4. They present their model as being developed from the VDI model. However, compared with the VDI model, this model better presents the steps and phases.
Figure 4-4: Design process according to [Pahl & Beitz 1999]

Focussing on the conceptual design phase, the following steps can be distinguished:

- Identify essential problems
- Establish function structures
- Search for working principles and working structures
- Combine and firm up into conceptual variants
- Evaluate against technical and economical criteria

Pahl & Beitz discuss their model in greater detail in the referenced text.
during the conceptual phase”) and that it is not always possible to avoid backtracking (“during embodiment design new auxiliary functions may be discovered for which principal solutions have to be found”).

4.3 Cross

The model for a product design process developed by [Cross 1992] is presented in Figure 4-5. He assumes a symmetrical relationship between problem and solution and between sub problems and sub-solutions (two way horizontal arrows). An attempt is made to demonstrate that the relationship is not one way, from problem to solution, but that problem definition is often dependent upon solution concepts. Contemplating possible solutions often helps to clarify the problem and reflecting on similar past (sub)problems and their (sub)solutions, supports the establishing of functions and setting of requirements.

![Diagram of Cross's model](diagram.png)

Figure 4-5: Product design process by [Cross 1992]

Just as the VDI, Cross distinguishes between problem and sub problems and between sub-solutions and overall solution. His model however, better emphasizes the interrelation between problem and solution. The seven stages presented by Cross can be interpreted rather as logical steps than temporal phases, although just as with the VDI model the distinction between steps and phases is not clearly made.

4.4 Roozenburg & Eekels

[Roozenburg & Eekels, 1998] present their basic cycle of design as a most basic fundamental model of the design process. Their model (Figure 4-6), derived from “the empirical cycle” discussed by [de Groot 1981] (Observation-supposition-expectation-testing-evaluation), is presented as being true for all design problems.
• Initiation phase (project definition and planning, user requirements & spec.)
• Conceptual design phase
• Detailed design phase
• Construction phase
• Operation phase
• Retirement phase

The conceptual design phase, the focus of this paper, is positioned between the initiation phase and the detailed design phase. Depending on the scale or complexity of the project, extra intermediate phases can be used, such as an extra project definition phase (before the conceptual design phase) or an embodiment design phase (after the conceptual design phase).

As already mentioned by Pahl & Beitz, it is difficult to draw clear borders between the phases and exactly define the input and output of each phase. However, the conceptual design phase usually starts with a project definition and planning produced by the previous phase. The previous (initiation) phase should also have produced some kind of problem statement and researched the need for the project, resulting in some kind of specification as to what is required from the system to be developed. At the end of the conceptual design phase, the best solution principle (or concept) is to be selected. Sometimes various possible concepts look equally promising, requiring more detailed development before a final decision can be made. In any case, the design activities continue on a more detailed level, referred to as the detailed design phase.

5.2 Steps within the conceptual design phase

Within the conceptual design phase, as within all other phases, several logical steps can be defined. Steps structure the conceptual design phase in a logical way. The steps (or elements of the fine structure [Hall 1989]) have no necessary chronological sequence but are generally carried out in an iterative fashion.

When comparing the models, it is clear that not all models distinguish between phases and steps in exactly the same way, nor do all models when discussing steps have the same logical structure. Although there are many differences, the models also have some things in common. The steps distinguished in the SE and ED models are presented in respectively Table 5-2 and Table 5-3.

Table 5-2: Distinguished steps for the conceptual design phase in SE models

<table>
<thead>
<tr>
<th>Hall (&amp;Sage)</th>
<th>DoD</th>
<th>INCOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Problem definition</td>
<td>• Requirements analysis</td>
<td>• Mission analysis &amp; definition</td>
</tr>
<tr>
<td>• Value system design</td>
<td>• Functional analysis/allocation</td>
<td>• Requirements analysis &amp; def.</td>
</tr>
<tr>
<td>• System synthesis</td>
<td>• Synthesis</td>
<td>• Concept analysis &amp; definition</td>
</tr>
<tr>
<td>• System analysis</td>
<td>• System analysis &amp; Control (incl. tradeoffs)</td>
<td>• Design</td>
</tr>
<tr>
<td>• Optimisation / (Refine. of Alternatives)</td>
<td></td>
<td>• Production (prototyping)</td>
</tr>
<tr>
<td>• Decision making</td>
<td></td>
<td>• Delivery</td>
</tr>
<tr>
<td>• Planning for action</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When comparing these steps, it is clear that the terminology and number of steps differ. Some models are general while others are more specific (more clearly presenting its origin). Some models present steps which are, when viewed fundamentally, not steps themselves but rather iterations of other steps (e.g. optimisation or improving alternatives). For this paper, it is impossible to elaborate on all steps presented in the models. For this I refer to the reference documents. However, when focussing on what the models have in common, and adopting the good points, the following basic steps can be defined:

- Problem analysis
- System definition
- Systems synthesis
- Simulation (systems analysis)
- Evaluation & selection

These steps can be used as a logical structure within the conceptual design phase. The content of each step is discussed in the next chapter.

5.3 Characteristics of the conceptual design process

Apart from the structuring of the design process using phases and steps, other interesting characteristics of the design process are also presented within the models, often by using a particular representation. The characteristics discussed here are iterations, divergence and convergence, perspectives and the decomposition of problems, solutions and systems and their interrelations.

Iteration
Iteration is the repetition of a process, using the results of the previous procedure to obtain a closer approximation to the solution of a problem. The model presented by Roozenburg & Eekels presents this in its most fundamentally correct from. Other models, although also discussing iteration, interpret it less strictly. Iteration in most models is not interpreted as a repetition of a mathematical or computational procedure, but rather as a recognition that the steps are not taken in one sequence. Models that clearly present iteration are the spiral model by Hall, the systems
engineering model by DoD and INCOSE and of course the basic cycle of design by Roozenburg & Eekels.

Some models present iteration as a step, to emphasize its importance. Examples are optimisation by Hall and improving details by Cross. However, iteration should not be considered a step in itself but rather a process containing two or more steps.

Although iteration is an important characteristic when considering steps, it is not the correct word to use for phases as phases are primarily sequential. As phases do interact where they overlap in time, "interaction" is a better word to use. For phases that do not overlap, "interrelation" is a better word for indicating a relation between phases.

Divergence and convergence
Divergence and convergence are both important for the conceptual design of a system. Convergence is important for the progress of a project. It is "necessary to produce useful output in the real world" [Hall 1989]. Divergence is however also important, especially within the conceptual design phase, as the choices made in the conceptual design phase influence all subsequent phases. In order to have something to choose from, it is important to develop several different concepts (divergence). Divergence and convergence within the conceptual design phase is clearly presented by the VDI (Figure 4-3).

Perspectives and professions (disciplines)
As clearly presented in the V process model by Sage, different perspectives can be distinguished as dominant for different phases in the design process depending on the level of detail. Although the V process model applies to phases, different perspectives can also be distinguished for steps within a phase. Not all steps within the conceptual design phase require the same perspective or level of detail. Furthermore, different disciplines or professions can be required. The 3D matrix by Hall presents the phases steps and professions in one graph. It is important to recognise that for large complex projects different disciplines, and therefore different groups of people, can dominate different steps within the conceptual design phase.

Decomposition of problems, solutions and systems and their interrelations
By recognizing that designing is not a linear sequential process but an iterative process involving feedback, an interrelation between problem and solution is already suggested. (it is easier to clearly (re)define the problem if you have a possible solution in mind). Cross attempts to show that problem definition is often dependent upon solution concept. Going back and forth between possible solutions and problem specification/definition helps to better understand the problem and produce better solutions.

Subdividing the problem into sub problems and the solution in sub-solutions (or the system into sub-systems when reasoning from solution to problem) helps to structure a complex problem. This is best shown by the VDI (Figure 4-2). Recognizing the interrelation between problem and solution and applying problem/system decomposition will surely facilitate the conceptual design process.
A basic framework for conceptual design is presented in Figure 6-1. This framework was developed using existing Systems Engineering and Engineering Design models presented in the previous chapters. It is a generic framework, in that it can be used for conceptual design in general.

6.1 The basic framework

First, conceptual design is presented as a phase of the total system life cycle. The conceptual design phase is positioned between the initiation phase and the detailed design phase. Although the phases can overlap, allowing for interaction between them, the phases are basically sequential. In an ideal situation, the phases always slightly overlap, making it possible to hand over and discuss the result from one phase to the next. As the conceptual design phase influences the many subsequent phases, it is important to recognise and understand all the phases and their importance in the total systems life cycle. During the conceptual design phase it is for example important to consider the operational phase, as this is usually where the money is made. For some systems, it is important to think about the dismantling and retirement of the system before it is built as this could a substantial part of the total lifecycle cost.

Figure 6-1: Basic framework for conceptual design
Within the conceptual design phase five steps are distinguished: Problem Analysis, System Definition, Systems Synthesis, Simulation and Evaluation & Selection.

The main aim of the problem analysis step is to understand the problem. Although a problem statement could (or should) have been formulated in the previous initiation phase, it is necessary to (re)formulate the problem in the conceptual design phase. This helps the conceptual design team to understand the problem and position it within its environment. It stimulates communication between the parties involved and ensures a mutual understanding of the problem. The problem analysis step produces the general goal of the project together with the need for the project. It distinguishes between the different parties involved and collects all (possibly conflicting) objectives, requirements, demands and constraints. This problem analysis step focuses on the outside world, collecting relevant data in order to clearly define the problem within its environment in a solution neutral way.

The system definition step focuses the project. It guides the search for alternatives by defining system borders, formulating basic assumptions and defining criteria for selecting the most appropriate system concept. Here the system is defined within its environment and the system functions and sub-functions are determined. Although this system definition step does not develop solutions, the functional structuring can be seen as an iterative process involving both, this system definition step and the next system synthesis step. (Iterations and other relations between the steps are discussed later in this chapter)

Synthesis is the combination of ideas to form a system. The systems synthesis step contains the collection of or searching for alternative sub-solutions and combining them into system concepts. Different system concepts (total solutions) can be created by combining different sub-solutions. The created concepts should permit a proper simulation and evaluation. Again, the development and optimisation of different concepts is often an iterative process involving more than one step.

Simulation, or systems analysis, produces the expected properties and characteristics of system concepts preceding the actual production and operation. For the conceptual design of complex systems, virtual prototyping or computer simulation is often used. Although computers are useful and powerful tools to analyse a system, simulation in principle does not necessarily involve computers. Simulation can more generally be interpreted as forming an image of the behaviour and properties of a system by reasoning or testing. (These images can often be merely based on generalisations from experience [Roozenburg & Eekels 1998])

Evaluation and selection involve comparing the expected properties and characteristics of the various concepts derived from simulation with the desired properties and characteristics (criteria). The different system concepts can be compared with one another relative to the criteria formulated within the system definition step, thus enabling a well-founded choice for one or several systems to be detailed in the next detailed design phase.

So far, there are no relations drawn between the steps presented in the basic framework. This was done to keep the structure simple and clear and avoid confusion.
6.2 Relations between steps for conceptual design

Although the five steps of the conceptual design phase have a logical structure, there is no necessary chronological sequence. The steps can be taken in many different ways and many different relations can be drawn between them. Figure 6-2 shows three different possible relations between the steps.

The main structure (left) connects the steps as if they were sequential from top to bottom, emphasizing their logical sequence. This main structure can be used to present the work done at the end of the conceptual design phase. The steps are shown from top to bottom, as if the work has been done in that order. Although this facilitates a logical and clear presentation, in reality the steps are almost never taken in such a precise chronological order.

Iteration is a repetitive process consisting of two or more sequential steps. Iteration is perhaps the most important relation for steps. This relation is presented in the middle of Figure 6-2, by using circular one way arrows tying two or more steps together with a circular motion. Optimisation or refinement are typical examples of an iterative process.

A third type of relation is presented on the right of Figure 6-2; interrelations. An interrelation is represented by a two way arrow between two steps. Interrelations are used to show that two steps influence one another but are not necessarily part of an iterative process within the same time window. Interrelation can exist between steps, but also between phases. For steps, the interrelation between problem and solution is a good example. For phases, the interrelation between the conceptual design phase and operational phase present a good example of two phases that influence one another while they are part of different periods in time.

Figure 6-2: Relations between steps
6.3 General remarks

Apart from this structuring of the conceptual design phase using steps, and the recognition of different possible relations between steps, two important aspects have not been mentioned.

Firstly, different perspectives or disciplines (and thus people) can and should be distinguished when developing complex systems. Although the basic framework does not reflect this, it is very important to recognise this. Some basic disciplines and perspectives for conceptual design of automated freight transportation systems are discussed in the next chapter.

Secondly, diversion and conversion are both very important within the conceptual design phase. As time and money are often limited within a project, choices have to be made. Choices made in the conceptual design phase influence all subsequent phases and are therefore very important. In order to have something to choose from, several alternative concepts have to be generated.
automated freight transportation systems

Although the basic framework discussed in the previous chapter presents a general well founded structure for conceptual design, more specifics are required to make it useful for the conceptual design of automated freight transportation systems. This chapter introduces some specifics for automated freight transportation systems. It is a first attempt to “fill in” the generic framework and should be considered a section for stimulating discussions.

7.1 Structure of a transport system: layers and functions

By modelling the transport system using layers, a structure can be presented where each layer facilitates the layer above and requires the layer beneath. Inspired by the layer schemes discussed by [Schaafsma et al 2001] the following layers are defined:

<table>
<thead>
<tr>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Market</td>
</tr>
<tr>
<td>Operational Organisation</td>
</tr>
<tr>
<td>Control system</td>
</tr>
<tr>
<td>Superstructures</td>
</tr>
<tr>
<td>Infrastructure</td>
</tr>
</tbody>
</table>

Figure 7-1: Layer model for Automated freight transportation systems

Automated freight transportation systems typically focus on the layers Control system and Superstructure. Automated freight transportation systems function within an operational organisation and require infrastructure.

For each layer, functions can be defined. Focussing on the superstructures layer, the main function can be defined according to [Prins 1976] as:

- Transport
- Handling
- Storage

Different functions can however be formulated for different layers or levels of detail. A clear functional structure for automated freight transportation systems still has to be developed.

7.2 Perspectives

Many different perspectives can be presented as important, when designing automated freight transportation systems. Discussed were different perspectives depending on phases, steps or disciplines/professions. Table 7-1 presents an overview of perspectives considered to be important for conceptual design of automated freight transportation systems.
### Table 7-1: Different perspectives to consider

<table>
<thead>
<tr>
<th>Phases in Lifecycle</th>
<th>Conceptual design steps</th>
<th>Disciplines involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed design</td>
<td>Problem analysis</td>
<td>Engineering</td>
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Project management should structure the project taking these perspectives into account.

#### 7.3 Criteria

For the evaluation and selection of alternatives, criteria are required. Table 7-2 presents some criteria considered useful for evaluating and selecting concepts.

### Table 7-2: Criteria

- Costs
  - Investment costs
  - Operational costs
- Performance
  - Capacity
  - Speed
  - Frequency
- Flexibility
  - Scalability / expansion
  - Business/market changes
  - Operational
- Reliability
  - Up time
  - Failure rates
  - Robustness
- Environmental impact
  - Land use
  - Energy consumption
  - Pollution
- Compatibility
- Maintenance
- Risk
- Safety
- Working conditions
- Sustainability
- ...

The project nature and the embedding of the project in society will determine the weight of the various assessment criteria.
This paper presents the development of a basic framework for the conceptual design of automated freight transportation systems. Based on existing Systems Engineering and Engineering Design models, a well-founded generic framework has been developed for conceptual design of technical systems. It positions the conceptual design phase as an important phase within the total system's life-cycle and helps to structure the conceptual design process.

The framework presented in Chapter 6 is generic, in that it can be used for the conceptual design of many different types of technical systems. Although generic models are desired from a scientific point of view, more specific and concrete tools are required in practice. Chapter 7 was added to introduce some aspects, specific for automated freight transportation systems. It is a first attempt to "fill in" or specify the more general framework and should be seen as a chapter intended to start meaningful discussion.

Future research focuses on further development and specification of the basic framework in order to produce a total design approach for the conceptual design of automated freight transportation systems. Useful methods and techniques will be added together with more aspects typical for automated freight transportation systems. The ultimate goal is to develop a useful aid for future conceptual design of automated freight transportation systems.
References


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