Andreas Silli, BSc

Development of a Modularization Concept and Product Configurator for an Innovative Normobaric High-Altitude Training System

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Supervisor
Dipl.-Ing. Mario Kleindienst
Institute of Industrial Management and Innovation Research
Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

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Kurzfassung

Diese Masterarbeit wurde in Kooperation mit der Firma AMST-Systemtechnik GmbH verfasst. Zu den existierenden Produkten des Unternehmens zählen unter anderem Trainings- und Simulationsgeräte wie Zentrifugen, Flugsimulatoren, Überdruck- und Unterdruckkammern und die Kunden stammen Großteils aus dem militärischen Bereich. Die Strategie des Unternehmens ist es, im Bereich der zivilen Luftfahrt Fuß zu fassen, sowie mit dem bestehenden Wissen über die Simulation von Höhe ein Trainingssystem für Leistungssportler zu entwickeln. Das System für normobares Höhentraining (NHT) nutzt Stickstoff, um den Sauerstoffanteil in der Atemluft an den äquivalenten Anteil von bis zu 4500 Metern Höhe anzupassen und steht im Zentrum der Betrachtung dieser Arbeit.

Bei der Entwicklung des NHT Systems spielt Modularisierung eine wesentliche Rolle, damit AMST verschiedenen Kundenwünschen gerecht werden kann. Dafür muss ein Werkzeug zur Konfiguration von verschiedenen Varianten, in Form eines Produktkonfigurators, entwickelt werden. Dieser Produktkonfigurator soll einfach zu nutzen sein und mit wenigen Eingabeparametern sämtliche Varianten des Höhentrainingssystems abbilden. Die Konfigurationsdatei soll eine Auflistung der wichtigsten Module sowie der entsprechenden Kosten beinhalten und in die AMST Arbeitsumgebung integriert werden.

Zu Beginn der Masterarbeit wird die bestehende Literatur zum Thema Innovation erläutert und die Möglichkeiten zur Entwicklung von Geschäftsmodellen nach Osterwalder vorgestellt. Der Business Model Canvas dient als Rahmenwerk, um ein Geschäftsmodell für das Trainingssystem zu erstellen. Als nächstes wird auf bestehende Richtlinien der Produktentwicklung und auf die Entwicklung von modularen Produkten eingegangen. Modular Function Deployment (MFD) dient als Leitfaden für die Entwicklung des Produktkonfigurators. Darauf folgt eine theoretische Einführung in das Höhentraining. Verschiedene Trainingsmethoden werden erläutert und der Einfluss von simulierter Höhe auf den Menschen untersucht. Im praktischen Teil der Arbeit wird ein Microsoft Excel Tool erstellt, um den Preis der jeweiligen Konfiguration, sowie die Module zur notwendigen Stickstoffzufuhr und Klimatisierung zu ermitteln.

Am Ende der Arbeit werden unterschiedliche Varianten des normobaren Trainingssystems auf Kostenbasis miteinander verglichen und Handlungsempfehlungen für AMST hinsichtlich der notwendigen nächsten Schritte, bis zum Marktstart der Trainingssysteme abgegeben.

Abstract

This master's thesis was authored in collaboration with AMST-Systemtechnik GmbH. The portfolio of the company includes training and simulation products such as centrifuges, flight simulators, hyperbaric and hypobaric chambers with customers predominantly from the military sector. The strategy of the company includes expanding the business area to civil aviation and moreover, to develop altitude training systems for civil applications, thanks to existing knowledge of high-altitude simulation. The Normobaric High Altitude Training (NHT) system uses nitrogen, in order to reduce the oxygen concentration in the air to simulate an equivalent altitude level of up to 4500 meters, which is a central observation in this thesis.

During the development of the NHT system, modularization plays an important role. Therefore, a tool for the configuration of different variants, in form of a product configuration, should be developed. This product configuration should be easy to use and furthermore, the different variants should be calculated with just a few input parameters. The result must show the most important modules and the production costs, and the tool should be integrated into the existing AMST work environment.

At the beginning of the master's thesis, existing literature covering innovation is unfolded and the business model canvas from Osterwalder & Pigneur introduced. The canvas for business model generation is used as a guideline to generate a business model for the NHT. Next, the different regulations for product development are outlined and the method of Modular Function Deployment (MFD) serves as a guideline for the practical part of the thesis. Thereafter, a theoretical introduction to high-altitude training follows. Different principles of training are explained and the influence of normobaric hypoxia to the human organism is outlined. In the practical part, a Microsoft Excel tool is developed, in order to calculate the costs of different variants, as well as the important modules, such as the nitrogen system.

At the end of the thesis, different variants of the NHT are compared on the basis of their comparative costs. Furthermore, recommended actions for AMST are provided with regard to the next steps towards market launch of the training system.

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Abbreviations

AMS	Acute Mountain Sickness
DSM	Design Structure Matrix
EPO	Erythropoietin
HH	Hypobaric Hypoxia
IH	Intermittent Hypoxia
IHE	Intermittent Hypoxic Exposure
IHT	Intermittent Hypoxic Training
IOC	International Olympic Committee
MFD	Modular Function Deployment
MIM	Module Indication Matrix
NH	Normobaric Hypoxia
NHT	Normobaric High Altitude Training
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
PSA	pressure swing absorption
QFD	Quality Function Deployment
RMT	respiratory muscle training
WBS	Work Breakdown Structure

1 Introduction

With collaboration from AMST-Systemtechik GmbH, a price calculation tool for an innovative Normobaric High Altitude Training (NHT) system was developed and the procedure is elaborated in this diploma thesis. Different perspectives have influenced the NHT system and therefore parts of innovation management, product development with a focus on modularization and high-altitude training are presented.

1.1 About AMST

AMST-Systemtechnik GmbH is an Austrian manufacturer of aircrew training equipment. The product range includes centrifuges, aircrew training equipment, products in the field of aero-medical training, accident prevention and recovery training, escape and rescue training systems and chamber systems for pilot training. To mention one of the most versatile products, Desdemona is the world's only g-motion platform with six degrees of freedom for powerful mission simulation and advanced flight training, with unlimited performance in yaw, pitch and roll. Desdemona is a single source solution for commercial and military simulation and can operate with accelerations and decelerations of three times greater than the speed of gravity. According to AMST, Desdemona is a motion simulator, disorientation trainer and advanced research lab, all in one. The picture in figure 1, shows the Desdemona, which was installed in the Netherlands in 2006. The main benefit of the Desdemona is the increasing need to familiarize the pilot, with the drastic effects of illusions frequently experienced and sometimes drastic phenomena of spatial disorientation in today's highly sophisticated flight operations (AMST, 2016c).

Austria Metall Sytemtechnik (AMST) was founded in 1987 when the state owned Austria Metall AG (AMAG) was branching out into engineering and aerospace. This was initiated by a large contract for developing a research centrifuge. Later in 1996, AMST was privatized to AMST-Systemtechnik GmbH by the Managing Director Richard Schlüsselberger sr. with a management buy out. The equity of Richard Schlüsselberger sr. was transfered equally in 2010 to both sons, Richard jr. and Rainer Schlüsselberger.

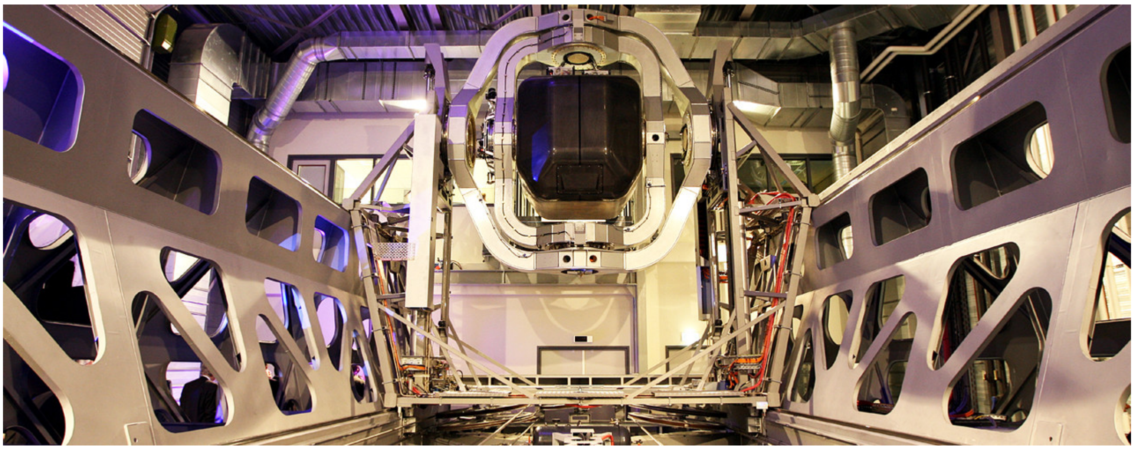


Figure 1: Desdemona: The Revolution in Simulation, AMST (2016c)

Modern military and civil aircraft are complex and the demands for preparation and pilot training are tremendous. To ensure the complete operational performance and safety of the aircraft and the operating flight crew, courses need to be prepared in order to optimize training. The developments of AMST encompass a large scope, from simulating high altitude experiences, spatial disorientation training and g-force simulations, as already mentioned with Desdemona.

Another excellent product to outline is the hypobaric and rapid decompression chamber. In general, the most serious danger for the aircrew is a decrease in partial pressure of oxygen, which can lead to incapacitation or even death. Supersonic speed enables military machines to reach altitudes far above 10,000 meters within a short time. If a loss of oxygen or cabin pressure occurs, the pilot has only a short time of useful consciousness available to react and make the correct decisions. With the rapid decompression chamber, this behavior can be trained in a safe environment, in order to prevent fatal accidents (AMST, 2016b).

AMST is trying to be innovative and continually attempt to further their evolution. Approximately eight percent of the annual revenue is invested in research and development and this has resulted in consistently pioneering new thresholds in training systems and design. Since AMST is a private company, a wide range of products have been developed. As AMST is already providing training and chamber systems, it is obvious to combine principles of these two products with the Normobaric High Altitude Training. The benefits when products are designed and developed by AMST include a high safety standard, high reliability and availability factors, low maintenance costs and appealing product design (AMST, 2016a).

1.2 Assignment and Objectives

This work is focusing on a possible new product series concerning innovative Normobaric High Altitude Training (NHT) systems and the development of a product configuration file for individualized systems. There have already been potential customers asking for a high-altitude training system, but their needs have been very different. The desired products range from mobile systems to large training facilities that include several rooms for altitude training and recovery or acclimatization. Considering this, the NHT needs a modular set up and ideas referring to the strategy of this new product. These thoughts can be implemented into the product configuration tool that finally calculates the production costs of the desired variant. This tool should include three types of the product. A mobile system, on the backside of a truck, a standalone container system and a system, integrated in existing infrastructure or training facilities.

The driving force behind this new product can be assumed. AMST has existing knowledge with hypobaric and rapid decompression chambers that have mainly been used for pilot trainings but not in the civil sector or the health and fitness industry (AMST, 2016b). Furthermore, the firms focus is shifting from execution and development of new projects to processing of existing products. To still serve the needs of highly sophisticated customers, a product like the NHT benefits from a modular product architecture. Furthermore, the knowledge generated in the processing of products, based on a modular system, is helping AMST in other business sectors like civil aviation.

Therefore the first step of this thesis was to take a view on the business model that could serve the product development. A business model for a modular NHT system should be developed in order to support the development of the configuration tool. With the help of the gained knowledge, it is easier to set up the modules and develop the configuration file that serves as a bill of materials and a tool for cost calculation. This tool should be easy to use and be able to process several variants of the training system. Additionally, it should be integrated in the AMST working environment and be adaptable for future configurations that may be desired.

As the chamber operates on artificial altitude, based on nitrogen enrichment of the air, the primary part of the calculation is referring to the nitrogen system. The volume flow depends on different factors such as the number of athletes, the type of training, the room size and the temperature. The configuration file needs to be integrated in the existing work flow of the company. That is why the existing work packages and cost centers need integration. In addition, the configuration file needs to be adaptable and easy to upgrade for further implementations.

1.3 Contents of This Thesis

In order to gain basic knowledge for product success, different literature is analyzed in this thesis. The beginning is constructed of a theoretical part regarding innovation and how to create it, including different processes and a strategy for innovation that leads to the importance of a business model which is finally generated with the template of Osterwalder. His business model canvas was used during a workshop at AMST, not only to develop a business model, but also to gain an overall understanding of the NHT. Furthermore, different types of innovation and business models are mentioned.

Because of the newness of this product, a look at development itself is taken which appropriately fits the necessity of a modular system. The method of Modular Function Deployment is chosen and implemented for the development of the configuration file. This method helps to understand the modularization principle, which determines the calculations necessary for each module.

To better understand altitude training, basic knowledge is provided, including physics of the atmosphere, what hypoxia is, as well as the difference between natural and artificial altitude. Additionally the literature that supports performance enhancement due to altitude training is presented. There exist different protocols for altitude exposure in order to increase performance and the most prominent usage for altitude chambers, live low - train high, as well as the others are explained.

As the theoretical part is defined, the configuration file is developed. First a look at the customer needs with the help of the business model canvas is taken before the modules are determined with Quality Function Deployment (QFD). The configuration file can thus be set up and the inputs and the layout implemented.

In the closing part, the output of different variants is presented. A low cost and a standard variant are compared and the price development in relation to the number of athletes and the room size is portrayed.

2 Innovation

In this first chapter the different types of innovation are explained and how a innovative strategy can be induced. Moreover the business model canvas from Osterwalder is explained because it is used to gain a good overview of the product later in this thesis.

The term innovation derives from the Latin words *"novus"* which means new and *"innovare"* which means renew. Out of this the word evolved *"innovatio"*, which means renewal and change through technological, social or economic transformation (Granig & Persuch, 2012, p. 21).

In literature many definitions for what innovation is are found and each definition depends on various aspects. Additionally the point of view on innovation is also important. From the perspective of science many studies are not comparable because of the different definitions utilized. Mostly a new product is implying an innovation without assessing the degree of newness. From the point of business practice the process itself and if there is a new usage or market for the product is important. Both perspectives are leading to the basic definition: *»Innovations are qualitative new products or processes, that can be distinguished from existing products explicitly.«* This first definition is focusing on the newness of a technology but does not include its application (Hauschild & Salomo, 2011, p. 4).

Due to this, it is also important to include the task that is performed with the new technology. Existing technology can be used for a new task or purpose and also be an innovation. It is simply the newness that counts and therefore Hauschild & Salomo talk about the **Dimensions of Innovation**. The *content-related dimension* answers **what** is new. The *intensity dimension* describes **how** new something is. With the *subjective dimension* it is described **for whom** it is new. The *procedural dimension* answers **where** the newness begins to where it ends and the *normative dimension* describes if new results in **success** or not. Each dimension has to be taken into account to tell if something is innovative or not (Hauschild & Salomo, 2011, p. 5).

The characteristics of innovation can be summarized with newness, uniqueness, new usage, complexity, uncertainty as well as a new customer segment (Granig & Persuch, 2012, p. 23).

2.1 Types of Innovation

There are different types of innovation and therefore, criteria to distinguish between them are needed. Granig & Persuch show a list that differentiates innovation according to criteria from table 1. They adopted the list from Vahs & Burmester (2005). At first, it can be differentiated in the **field of innovation** (Granig & Persuch, 2012, pp. 24 - 26).

Differentiation in ...	
... the field of innovation	Product Innovation Process Innovation Cultural and Social Innovation Structural Innovation
... the trigger of innovation	Pull-Innovation Push-Innovation
... the degree of innovation	Base Innovation Improvement Innovation Adaption Innovation Imitation Fake Innovation
... the change of innovation	Incremental Innovation Radial Innovation

Table 1: Differentiation of Innovation, own translation (Granig & Persuch, 2012, p. 24)

Product Innovation happens, when a new product is launched to the market in order to serve the customers' needs. The characteristics of a product include the *core of the product* with its technical and functional properties, the *design of the product*, which means the appearance to the customer, and the *additional services* that improve the attractiveness of the product. When the problems of product characteristics are solved, this is product innovation, which can be caused by differentiation, variation, unification or standardization of the existing products on the market.

Process Innovation is the restructuring of the firms processes for improvement of efficiency and cost with sustaining the best degree of quality. Pleschak & Sabisch criticize that process innovation is neglected for product innovation which can lead to a lack of competitiveness. In reality, product and process innovation influence each other. For example, a new treatment (product innovation) in a hospital results mostly in a new process.

Social innovation affects all people, groups and organizations and their behavior. The primary goal is to increase the satisfaction of the employees and the safety of the workplace.

Structural Innovation is focusing on the organizational structure with a close relation to process, product and social innovation. The example of a hospital shows a social, as well as a structural innovation in the cooperation of different professional groups.

Furthermore, innovation can be differentiated in the **trigger**, such as a market-pull or a technology push. It is important to consider both triggers of innovation for success (Granig & Persuch, 2012, p. 26).

Pull-Innovations are induced from the market. Customers have a demand that is supplied and therefore this type of innovation has a high rate of success. A demand from market already exists and an example of which is a new product for pain relief without the common side effects.

Push-Innovations are induced with new technologies and therefore it is also called a technology push. A new field of application must be found, because most of the time, the innovation already exists in the form of a base or radical innovation. The demand from the market must be generated for this new product.

As in table 1, a differentiation is also possible with the **degree of innovation**. The newness of an innovation is important and it can be distinguished between the following differences (Granig & Persuch, 2012, p. 27):

Base Innovation describes the degree of innovation, when there is a new technology or principle involved. After a base innovation, often an improvement innovation follows. Theory suggests, that "long waves" or also called Kondratiev waves, can describe base innovations. Nefiodow (1996) suggests, that these cycle-like phenomena include five markets: information, environment, biotechnology, optical technology and health. He proposes to include a sixth wave for psychosocial health.

Improvement Innovation is mostly done through optimization of a base innovation. The initial functions and properties are not changed.

Adaptation Innovation is a variation of an existing product in order to adapt to special needs. This is often realized through modification, which is similar to improvement innovation.

Imitation is the customization and optimization of existing solutions for one's own business. In principle, an imitation is no innovation, but imitating companies can be innovative.

Fake Innovations are not generating additional value for the customer. An example is newly designed packaging for medications.

Additionally, the types can differentiate in the **change of innovation**. Dependent on the effort needed to realize innovation, it is either an incremental innovation or a radical innovation (Granig & Persuch, 2012, pp. 27 - 28).

Incremental Innovation is using technologies that have already been used and are therefore not new. Incremental innovations have a low risk because they concentrate on existing markets and fields of application.

Radical Innovation is something completely new that opens new markets. This real innovation has a higher risk.

2.1.1 Different Processes

The first generation of innovation processes was invented in the sixties and first used by National Aeronautics and Space Administration (NASA). The first processes were simply divided into different phases with a review after each phase. Later, they were used by the military and companies like Hewlett Packard. The phase models were helpful to standardize communication with suppliers and customers (Verworn & Herstatt, 2000, p. 2).

Stage Gate Process from Cooper

The second generation was developed from applied studies by Cooper et al. (1987). Successful and unsuccessful companies were compared and a standardized process was identified as the factor of success (Verworn & Herstatt, 2000, p. 3). This standard Stage-Gate™ for product development is shown in figure 2 and has five stages and gates with added stages for ideation, called *discovery* and a *post launch review* at the end. For smaller projects there of course exist shorter versions of this process (Cooper, 2008, p. 215). The Stage-Gate™ process is an improvement from first generation phase models, because it is interdisciplinary and includes, for example, marketing and production (Verworn & Herstatt, 2000, p. 3).

With the *stages* the innovation process can be visualized. Cooper proposes to think about the stages as plays in an American football game: They are well defined, have clear goals, a purpose and can be executed. As in figure 2, each stage has a *gate* following. In football language they would be

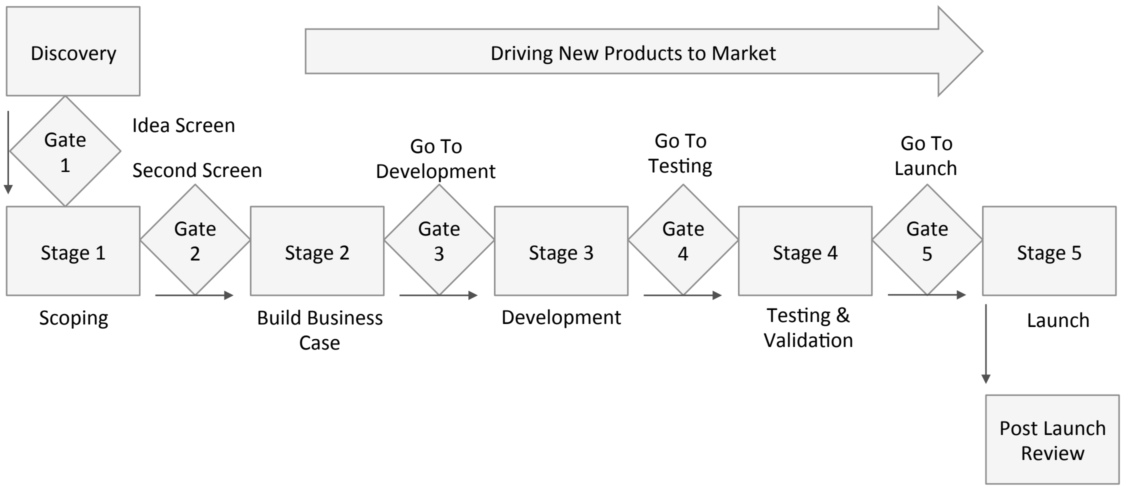


Figure 2: For New Product Developments: Current Stage-Gate™ System, own illustration (Cooper & Kleinschmidt, 1990, p. 46)

the huddles where decisions for the upcoming play are made. Gates serve as go or kill and decision points, and as points where the path for the future stages are determined (Cooper, 2008, p. 215).

In practice, the Stage-Gate™ process has its strengths in systematization and transparency to generate a common understanding in the development process. This improves the communication within the project team as well as with the top management. Studies have also shown that companies, such as IBM, 3M and General Motors, who have a good implementation of the Stage-Gate™ process, are more successful than companies who use no standardization in their product development processes (Whiteley et al., 1998, p. 16).

In reality, the phases of the Stage-Gate™ are not strictly separated and overlap in most projects. This is called the third generation of innovation processes and due to the more realistic approach they are easier to implement into a company. Even Coopers third generation Stage-Gate™ has more of the characteristics of a guideline then a standard (Verworn & Herstatt, 2000, p. 5).

Three Phases from Thom

Besides the popular Stage-Gate™ Model, there exist many other phase models but the model from Thom (1992) is mentioned. In German literature this process, developed in the 80s, is the most common and a translation is displayed in figure 3. The focus in each of the three phases is on the *idea*. The main phases are the *idea generation*, the *idea acceptance* and the *idea realization*.

Phases of Innovation Processes					
Main Phases					
1	Idea Generation	2	Idea Acceptance	3	Idea Realization
Specification of the Main Phases					
1.1	Identification of Search Field	2.1	Idea Examination	3.1	Realization of Idea
1.2	Brainstorming	2.2	Realization Plans	3.2	Sales and Distribution
1.3	Concept Generation	2.3	Decision on one Plan	3.3	Acceptance Test

Figure 3: Three Phase Innovation Process Model, own translation (Thom, 1992, p.9)

The main phases are further detailed into the identification of the search field, brainstorming and concept generation. The second phase is divided into idea examination, realization of different plans and the decision on one final plan. In the last phase the idea is realized, then distributed and sold and an evaluation of the acceptance is done (Verworn & Herstatt, 2000, p.7).

Further Phase Models

There are more detailed models in the subdivisions of the process steps. Brockhoff (1999) with his four phases of *project idea*, *research and development*, *invention*, *investment*, describes the possibility of a project stop after each of the phases. After the *investment* phase, which means manufacturing, marketing and selling the product, it is also evaluated as to how successful it was (Brockhoff, 1999, p. 36).

Vahs & Burmester (2005) also describe an innovation process. The specialty in this process was the controlling that surrounding each of the other phases (Vahs & Burmester, 2005, p. 89)

Furthermore, there has to be mention of a very comprehensive phase model from Pleschak & Sabisch and the innovation process after Herstatt & Verworn. Summing up, each one of the phase models is very similar to the basic Stage-Gate™ process from Cooper (Verworn & Herstatt, 2000, p.11).

2.1.2 Innovative Strategy

In a Harvard Business Review article, Pisano wrote about the importance of an innovation strategy. As the past has shown it is pretty hard to sustain performance in terms of innovations, even for successful innovators such as Polaroid, Nokia or Hewlett-Packard. The author states that the cause is not the lack of execution, but rather the missing strategy behind the innovation. Companies are also adopting to the best practices they may have seen or just imitating famous innovators (Pisano, 2015, p. 4).

Connect Strategy with Innovation

The development of an innovation strategy should be treated with the same priority as the creation of any good strategy. The specific objectives should be understood in order to achieve a competitive advantage that is sustainable. This robust innovation strategy, Pisano suggests, should be able to answer these questions:

How is the value created for potential customers? There are many ways to create value, better performance, easier to use, more reliable, cheaper, and so on, to name just a few. As the innovation can not create every value, it is important to stick to the kind of value that is critical for success of the innovation. The capabilities for each value are quite different and therefore it takes more time to accumulate them. For instance, Apple is continuously focusing on the usability of their products. Because of their own hardware and software development, these two main drivers of their products work seamlessly together in order to create a unique customer experience (Pisano, 2015, p. 7).

How will the company get a share of the innovations generated value? When an innovation creates value, imitators are attracted as quickly as customers. Most of the time, intellectual property is not enough to block the competitors. After the success of Apple's iPad, many other similar products were appearing. It is furthermore about the complementary assets, capabilities or products that convince the potential customers. Apple designs an ecosystem where it is more attractive to buy an iPad, rather then any other tablet, especially if a customer already uses other Apple devices. One of the best ways to maintain loyal customers is to continue to invest in innovation (Pisano, 2015, p. 8).

What types of innovation will allow to create and capture value? Clearly, innovation in technology is always creating a lot of economic value because of the competitive advantage gained. But there are also important innovations that have nothing to do with new technology.

Many companies like Netflix, Amazon or Uber simply mastered the art of business model innovation. Therefore companies have to split up their efforts to invest in *business model innovation* and *technological innovation* (Pisano, 2015, p. 8).

Types of Innovation

Different types of innovations are displayed in figure 4. This so called *Innovation Landscape Map*, was developed by Pisano with inputs from Christensen & Bower, Baldwin & Clark, Abernathy, Henderson and Tushman. The map has two dimensions characterizing innovation. The first dimension is the degree of the business model change and the second dimension is the degree of the change in technology. There are four suggested categories of innovation:

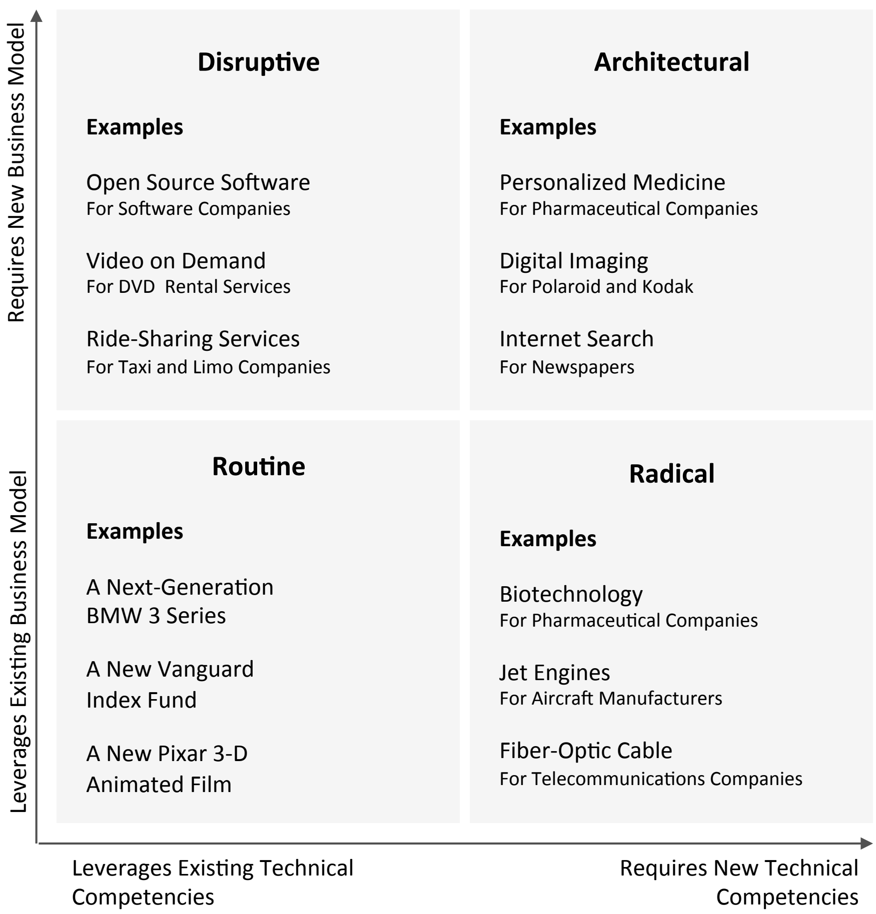


Figure 4: The Innovation Landscape Map, own illustration (Pisano, 2015, p. 9)

A *Routine Innovation* uses existing technology and combines it with a existing business model to serve a customer base. A example would be a new version of the iPhone or Microsofts operating system Windows (Pisano, 2015, p. 8).

The term *Disruptive Innovation*, named by Christensen & Bower (1995) is a type of innovation that requires a new business model but has no necessity for a new technology. It challenges and disrupts the business models of other companies (Pisano, 2015, p. 8). For example, Skype disrupted the telecommunications business model because its service was much cheaper. It was operating as a telecommunication provider under the circumstances of a software company (Osterwalder & Pigneur, 2010, p. 99).

Radical Innovation is kind of the opposite to disruptive innovation. It is all about a new technology and the business model does not matter very much. *Architectural Innovation* is a combination of a new business model with a new technology. Pisano gave a good example with digital photography. Kodak and Polaroid had to deal with the digital world in terms of camera design, software, electronics and display technology and they also had to figure out how to generate revenue from only the cameras without customers who needed to repeatedly buy film materials (Pisano, 2015, p. 8).

Because of the two dimensions of innovation strategy, the companies have to make a decision about how much effort they put into technological innovation and how much they invest into a business model. *Routine innovations*, in fact, contribute towards the vast majority of companies' revenues. Intel processors, or Microsoft operating systems can serve as examples (Pisano, 2015, p. 9). This thesis will continue with business model strategy in section 2.2, but it will first be explained as to why the technological innovation is not the predominant problem and why there is a challenge in leadership to be innovative.

How to Force Innovation

In another Harvard Business Review article entitled *"Innovation Isn't an Idea Problem"*, Burkus states that most of the time when companies try to force innovation they think they need more ideas. However, the lack of ideas is not the problem. For the most companies, the ideas are already there but nobody recognizes them. In the article some examples from history are listed.

Back in 1975, Kodak has invented the first digital camera and did not see it as an innovation. Instead Sony built a pretty similar prototype and pushed into the new marked of digital photography and Kodak did not react soon enough. The first personal computer was developed by Xerox, but Apple's Steve Jobs recognized the innovation and invested much more into this new technology in order to grasp the opportunity from Xerox (Burkus, 2013, p. 1).

Burkus referes to a research paper from Mueller et al. that states that everyone is biased against new and creative ideas if there is even the smallest uncertainty about them. For the study people were divided into two groups. One group was told that there existed a small extra payment and the people who receive this extra payment will be revealed after the test results are evaluated. They were biased and the test tried to evaluate if the participants either came up with creative or practical solutions. The outcome was that the biased people mainly preferred the practical, well known solutions, but found that the creative solutions could be better (Mueller et al., 2011).

If this influence of a possible extra payment is enough to force people to stick to the well known and refuse new, creative ideas, then this could be the explanation why so many ground breaking innovations were initially rejected. There is the assumption that great ideas in companies already exist, but the right people to force them and weaken the biases are missing (Burkus, 2013).

Innovative People

»How do I find innovative people for my organization? And how can I become more innovative myself?« - are according to Dyer et al. the questions senior executives ask themselves because they understand the importance of innovation for business success. In order to answer how famous and visionary entrepreneurs like Steve Jobs, Jeff Bezos from Amazon and eBay's Pierre Omidyar work, Dyer, Gregersen and Clayton conducted a six-year study to discover the inner workings of these masterminds. One of the main questions was how an entrepreneur who built Amazon differs from other executives and entrepreneurs. They questioned approximately 3000 executives of innovative companies and studied the habits of 25 innovative entrepreneurs.

In the article, *The Innovator's DNA*, they reveal the five so called discovery skills the most creative entrepreneurs and executives share. The first skill is *associating* and describes the ability to connect questions, problems and ideas that at first seem unrelated. For example, Steve Jobs, who spent his lifetime studying very different fields like calligraphy, the details of a Mercedes-Benz and meditation, was able to generate idea after idea because of the associations he made. *Questioning*, as the second discovery skill, allows entrepreneurs to get the right answers to the right questions. Especially founders of technology companies, such as eBay, Skype and PayPal like to question everything outside of the status quo. With the skill to *observe*, executives gain tremendous insights into behaviors of potential customers. The fourth skill is *experimenting* that encourages innovators to try new ideas and gain experiences from it. Thomas Edison once said that he has not failed, he just found 1000 ways to not do the work. Lastly, through *networking* with a variety of people, innovators gain insight into a radically different perspective (Dyer et al., 2009).

Pisano (2015) also writes about the importance of strategy at the end of his article. The question, who has to come up with innovative strategies, is quickly answered by him as the senior leaders of the company. To layout a business strategy there are several models the executives can use in order to be innovative. That is why the next section is about the importance of business models.

2.2 Importance of Business Models

To be successful in business it is essential to be innovative with the business model. Therefore the approaches to develop such models have increased over the last years. Due to increasing transparency of products and services, a high price depression, shrinking markets and a lack of opportunities for differentiation, companies are forced to walk along other paths to stay competitive. Good products or services are not enough anymore (Schallmo, 2015, p. 7) .

When typing *business model* in any web search, the first suggested term is *Business Model Canvas*. Osterwalder, in his thesis is writing about his business model ontology and has developed the *Business Model Canvas* based on his research. This section covers this particular way to describe a business model in detail and provides further information regarding the topic.

2.2.1 History of Business Models

To first define the term business model, Ovans (2015), in the recently published article *What Is a Business Model?*, answers this question by looking at the history of business models and how they were defined in previous years.

The most obvious way to research definitions nowadays is in a online dictionary, which subsequently offers the following - *»a design of the operations of a business which focuses on how revenue will be generated«*. Related to this first definition it can be said that the term *business model* is focusing on the operations to generate revenue. A restaurant for example, cooks and serves food to hungry customers in order to make money (dictionary.com, 2016).

Lewis offers another very simple and similar definition - *»All it really meant was how you planned to make money«* - when he was making a point about the dot.com bubble in his book. Most Internet companies' business models were to gain a lot of visitor traffic to their web site and sell the advertising space to others. Back in 2000, it was not clear that this model is going to make sense. A way to think about a business model is similar to thinking about art. Like art, most people will are able to recognize it, but are not able to create it on their own (Ovans, 2015, p. 1).

Drucker (1994) defined the term as - *»assumptions about what a company gets paid for«*. That is part of his *Theory of the Business* article in Harvard Business Review where he actually never mentions the term business model. The assumptions from Drucker about what a company will and will not do are close to the *Definition of Strategy* by Porter. Porter (1996) argues that the essence of strategy is to have unique combinations of actions that can not be matched easily, which correlates with a business model where you should not just look at one part but on the whole picture. It just correlates, a strategy is not the same thing as a business model (Magretta, 2002, p. 2).

In the article, *Why Business Models Matter*, Magretta states that business models are basically stories that explain how enterprises are working. The story should cover who the customer is, and what they value. Furthermore it should cover how to make money. These are the same questions Drucker is asking. Magretta also likes to think more about the assumptions than about money and says a business model has two sides of assumptions. The first side focuses on making something, and the second side focuses on selling something (Ovans, 2015; Magretta, 2002).

Alexander Osterwalder & Pigneur, as mentioned before also describe a business model with a set of assumptions or hypotheses. In a short article, *A Better Way to Think About Your Business Model*, it is mentioned that global companies like GE, P&G and Nestle use the Canvas for managing strategy and to develop new growth possibilities (Osterwalder, 2013, p. 1). Osterwalder & Pigneur offer the definition *»A business model describes the rationale of how an organization creates, delivers and captures value«* (Osterwalder & Pigneur, 2010, p. 14). His nine-block *Business Model Canvas* organizes assumptions not only about the key resources and key activities of the value chain, but also the customer segments, customer relationship, channels, value proposition, key partners, cost structure and revenue stream. This offers a very comprehensive approach to display assumptions about how to make money. With this method it is easy to see if something is missing and furthermore, if it is possible to compare one's business model to another's (Osterwalder & Pigneur, 2010, p. 16).

Magretta states that once someone starts to compare business models they are entering strategic thoughts. To distinguish, business models simply deal with how the business is running and a strategy deals with how to run better than someone else. A first strategy is to offer the same business model to a different group of customers. Another strategy is to offer a better business model to the same customers (Magretta, 2002, p. 9). This second strategy is also called *disruptive innovation*. This term, that defines an innovation that confuses an existing market was first defined by Christensen & Bower (1995). More information about disruptive innovation can be found in section 2.2.4. To reinvent a business model the first step is to focus on the customers value proposition, or what the customer wants to be done. Afterwards how to generate revenue is important and to optimize the process and the resources that make the new product better and harder to copy again (Christensen et al., 2008, p. 53).

2.2.2 Creation of a Business Model Scheme

The dissertation from Osterwalder introduces a integrated model that is able to describe different businesses. At the time of developing this model it was called the business model ontology (Osterwalder, 2004, p. 2). The first step to create this ontology was to set up categories that are able to describe the business model of a firm. The four main pillars from table 2 include the *product*, the *customer interface*, the *infrastructure* and *financial aspects*. They are influenced by the Balanced Scorecard approach from Kaplan & Norton and business model literature from Markides.

Balanced Scorecard Kaplan & Norton (1992)	Markides Markides (1999)	Business Model Ontology Osterwalder (2004)
Learning and Growth	What?	Product
Customer Perspective	Who?	Customer Interface
Internal Business	How?	Infrastructure
Financials Perspective		Financial Aspects

Table 2: Four Pillars of Business Models, adapted from Osterwalder (Osterwalder, 2004, p. 42)

The **Balanced Scorecard** describes an approach that should help managers to monitor not only the financial activities. It is a holistic tool to measure different perspectives of performance. With the balanced score card, four questions should be answered. How the customers are seeing the company is answered in the *customer perspective*. What the company must excel at is answered with a look at the *internal business*. In the *innovation and learning perspective*, if the company is able to continue with improving and generating value is addressed. And of course, the *financial perspective* that mainly describes how the company is looking to shareholders (Kaplan & Norton, 1992, pp. 73 - 75). Osterwalder took this perspectives as a base for his business model scheme. In a later work, Kaplan & Norton (1993) even proposed to use their balanced scorecard as a kind of blueprint for other business model schemes (Osterwalder, 2004, p. 42).

In the article, Six Principles of Breakthrough Strategy, Markides is asking three very simple questions. To ask for the **"who"**, **"what"** and **"how"** of a business is important. Who is the target customer? What products or services should the company offer to these customers? And finally, how can these products or services be delivered to the target customer? If the financial aspect is added to this questions this approach is pretty similar to the Balanced Scorecard (Markides, 1999; Osterwalder, 2004). In table 2 the approaches from Kaplan & Norton (1992) and Markides (1999) are compared to the ontology of Osterwalder (2004) and serve as a starting point.

Nine Building Blocks

Osterwalder wanted to go further into detail and split up the four pillars of the business model ontology into nine business model blocks. These blocks have relations among themselves. The four pillars are categories, whereas the detailed description of a business model is to be found within the following nine blocks: Value Proposition, Target Customer, Distribution Channels, Relationship, Value Configuration, Capability, Partnership, Revenue Model and Cost Structure. With these blocks Osterwalder summarized and drew lines to business model literature from figure 5 (Osterwalder, 2004, p. 43).

In the book *Business Model Generation*, the ontology was renamed into a canvas and the blocks also received slightly different names, but they are describing the same principles. Osterwalder & Pigneur (2010) came up with this separation to set a good starting point for any discussion, workshop or meeting. It is a simple concept everyone can follow and discuss. The nine blocks can be used for developing new or document existing business models and describes the basics of a firm's product, infrastructure, customers and finances. In table 3 the four pillars with the more detailed building blocks can be seen.

Evaluation of Literature

To generate his ontology, Osterwalder did an intensive literature review. He looked at the building blocks that the other authors were proposing and tried to take them into account when designing his own model. The final output of this approach resulted in the nine mentioned blocks, whereas each block of the ontology was at least mentioned twice by the literature. The output of this research can be seen in figure 5 (Osterwalder, 2004). After listing the nine building blocks, a closer look at each one must be taken in order to design or think about one's own business modeling.

A business model, by Weill & Vitale (2001), is a relationship description between the firms customers, partners and suppliers to identify the flows of product, money and information.
Linder & Cantrell (2000) made a difference between three types of business models. When speaking about a business model, people can refer to the components of a business model, the real operating business model, and so called change models. Gordijn et al. (2000) mention, that

Business Model Ontology	Value Proposition	Target Customer	Distribution Channel	Customer Interface	Value Configuration	Capability	Partnership	Cost Structure	Revenue Model
Afuah and Tucci 2003	Customer Value	Scope			connected activities, value configuration	capabilities		cost structure	pricing, revenue source
Applegate and Collura 2000	Product and Services offered	Market opportunity	Marketing/sales model	Brand and reputation	Operating model	(Organization and culture, management model)	Partners		Benefits to firm and stakeholders
Chesbrough and Rosenbloom 2000	Value proposition	Market segment			Structure of the value chain		Position in the value chain	Cost structure	
Gordijn 2002	Value offering	Market Segment			e3-value configuration		Actors	Value exchange	value exchange
Hamel 2000	Product/market scope	Market scope	Fulfillment & Support, into & insight	Relationship dynamics	Core processes	core competencies, strategic assets	suppliers, partners, coalitions		Pricing Structure
Linder and Cantrell 2000	value proposition		channel model	commerce relationship	commerce process model				pricing model, revenue model
Magretta 2002	What does the customer value?	Who is the customer?	How can we deliver value at an appropriate cost?					What is the underlying economic vale?	How do we make money in this business
Mahadevan 2000	Value stream				Logistical stream				Revenue stream
Petrovic, Kittl et al. 2001	Value Model		Customer relations model	Customer relations model	Production Model	Resource Model			Revenue Model
Stähler 2001	Value Proposition				Architecture		Architecture		Revenue Model
Weill and Vitale 2001	Value Proposition, strategic objective	Customer Segments	Channels			Core competencies, CSF	e-business schematics		Source of revenue

Figure 5: Nine blocks compared to other literature, adapted from Osterwalder (Osterwalder, 2004, pp. 45-46)

Pillar	Business Model Block	Description
Product	Value Propositions	This block describes the products and services that serve the customer needs for a specific segment. Value propositions are delivered to customers through channels.
Customer Interface	Customer Segments	An organization has to think about different groups of people or organizations it aims to reach and serve
	Distribution Channels	How a company aims to communicate and reach its customer segments in order to deliver value proposition.
	Customer Relationships	It is important to establish and maintain customer relationships with each segment. This block describes the types of relationships a company establishes.
Infrastructure	Key Activities	This block describes the most important things a company must do to make its business model work.
	Key Resources	These are the assets required to offer and deliver the previously mentioned elements.
	Key Partnerships	This block describes the supplier network and the most important partners to make the business model work.
Financial Aspects	Cost Structure	The elements of a business model result in a cost structure.
	Revenue Stream	If a value proposition is offered successfully to customers this results in revenues streams. It is a representation of the cash that is earned.

Table 3: Nine Blocks of the Business Model Canvas, compare to Osterwalder (2004)

in industry practice business models are mostly misunderstood and more interpreted as process models of how a business should be working. Petrovic & Kittl (2001) are describing the business model as the logic of a business system to create value (Osterwalder, 2004, p. 25).

A business model by Applegate (2000) is a description of a complex business that enables one to study every aspect of it. Stähler (2001) reminds that a model is just a simplification that helps to understand the underlaying structure of a business and support future planning. Additionally, Magretta (2002) states that a business model should tell a story. Not all of the authors include the financial aspect. Afuah & Tucci (2003) stated that a company that uses Internet services should have an Internet business model that focuses on the activities to make money (Osterwalder, 2004, p. 25).

Mahadevan (2000) indicates that the minimum required business model must contain a value stream, logistics stream and revenue stream (Osterwalder, 2004, p. 30). A simple list for a business model comes from Chesbrough & Rosenbloom (2000). Their list of six contains the identification of the market segment, the value proposition, the value chain, cost structure and potential of profit, the competitors and partners and as a final element: the competitive strategy (Osterwalder, 2004, p. 31).

Osterwalder also mentions the approach from Hamel (2000) to be interesting. A business model is an idea put into practice with the help of four business model components. These interrelated components are the core strategy, strategic resources, customer interface and value network. The connections, which Hamel calls bridges, are configuration, customer benefits and company boundaries. Like this, an inclusive approach to business models is recommended by Linder & Cantrell (Osterwalder, 2004, pp. 32-33).

2.2.3 The Business Model Canvas

The business model ontology consists of interrelated elements. The nine elements were previously mentioned and figure 6 shows how they interact. The right side of the canvas is related to external sources that mainly depend on the customer. On the contrary, the left side is related to internal source in order to generate the value propositions. In this section each of the elements will be briefly described.

Value Proposition

The value proposition is the first of the nine elements and the only one in the product category. Kambil et al. (1996) describe the value proposition as the definition of how products and services can solve customers problems and satisfy their needs. The model of the value proposition from Osterwalder is a conceptual approach that could answer why a customer is preferring to buy a product or service from one company and not from the other. To differentiate between value propositions the attributes description, reasoning, value level, price level and life cycle are used (Osterwalder, 2004, pp. 49-50).

The **reasoning** element describes why a company thinks its product or service is of value to

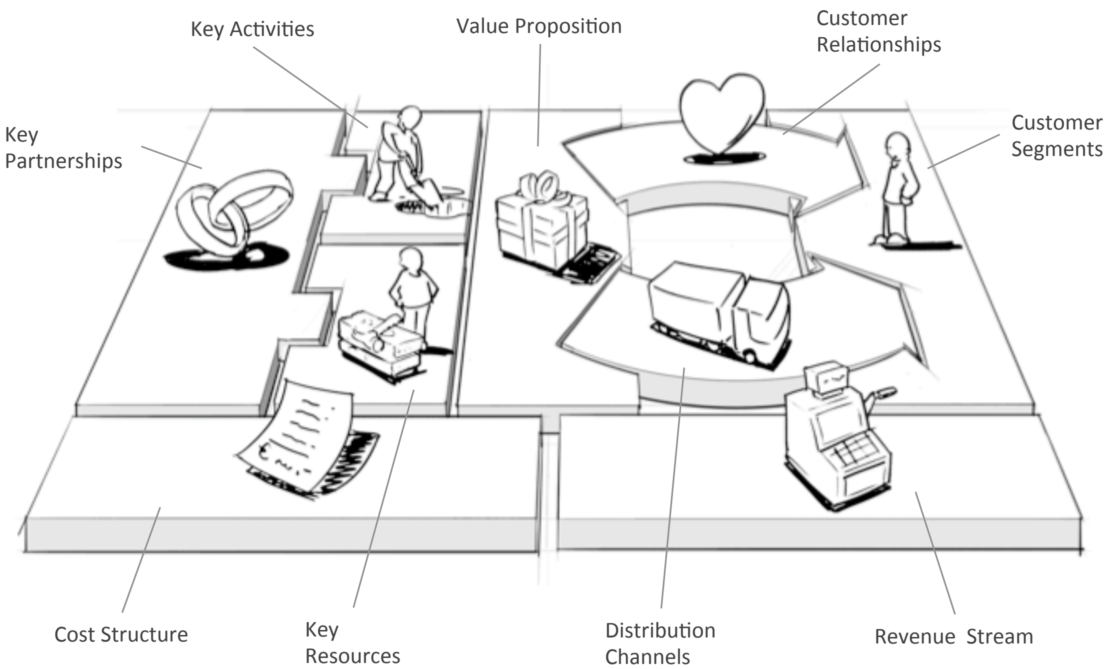


Figure 6: Business Model Sketch (Osterwalder & Pigneur, 2010, pp. 18-19)

the customer. This value can be created by the ability to use a product, for example traveling with a bicycle. Another value is if the customers risk is reduced, for example, a type of insurance. The reduction of the customers effort, for example with food deliveries, is also generating value (Osterwalder, 2004, p. 51).

The **value level** of a firm's product or service can be measured. According to Osterwalder the measurement should not happen quantitatively, rather he introduced a qualitative scale. This scale ranges from *commodities*, to *innovative imitation*, like Dell did with selling customizable computers over the Internet. It continues from *excellence*, like expensive watches, to *real innovations*. Innovation is happening right now at a very popular company. Tesla is combining its electric car with extensive software and furthermore is trying to use this car to convert the customers perspective on clean energy. With the existing energy storage system and the acquisition of solar city, customers of Tesla would also be able to produce their own fuel for their cars (Gans, 2016, pp. 2).

A product or service is also comparable with the **price level** attribute. Certain business models offer a *free* value proposition to the customer because revenues are generated in another way. A free newspaper generates revenue with advertisements. Another example for a free product is software, like open office, or linux. They are not generating revenue at all and the software is free to download via Internet. The price level can also be in the *economy range*, which means cheaper products than the competitors. This is different to the *market range*, a price that hits exactly the level the customer is willing to pay. Pricing at the market needs a more attractive product because it is not cheaper then the competitors product. A *high end price* represents the upper boundary of the price levels (Osterwalder, 2004, p. 53).

Anderson & Narus (1998) suggest to study the value proposition should over the entire **life cycle**. The value creation mainly happens at one of the five stages in a value life cycle. It can happen at the *creation*, the *purchase*, the *usage*, the *renewal* or the *transfer* of the value (Osterwalder, 2004, p. 54).

A customer has many possibilities to buy a product or service that satisfies him, and the value proposition should describe why the customer should choose one company over another. Osterwalder & Pigneur listed some example value propositions (Osterwalder & Pigneur, 2010, pp. 23-25):

Newness There are value propositions that may satisfy a complete new set of needs. Customers did not know they had these needs because there was no similar offer in the past. Most of the time this is technology related, for example smartphones. Sometimes it does not have anything to do with technology at all, like ethical investment funds.

Performance In the previous years of the personal computer sector, an increase in performance was the traditional way to generate more value for the customer. Nowadays a performance improvement is not enough in the PC market to generate more sales.

Brand A brand can be very important for some customer segments. Wearing an expensive watch like a Rolex can signify wealth.

Price When a lower price can be offered for the same product a customer is more likely to buy the less expensive product. Whole business models can be designed around low-price or also free products.

Accessibility The product availability, which may have not been present in the past, can also create value for the customer. For example, mutual funds provide accessibility for customers with modest wealth to a diversified investment portfolio.

With a separate book, *Value Proposition Design*, Osterwalder et al. (2014) explained in detail what it takes to create a good value proposition for the customer. A two sided approach is used where the customer description is opposed to the value generation.

With the big data revolution it should be easy to adjust to the customer. Companies are already collecting a enormous amount of data but firms are heading in the wrong direction because they are not using the data correctly. A company needs to analyze the *jobs to be done* and big data can be a very good starting point. To discover what jobs the customer needs to do, these five questions from Christensen et al. can help.

Is there a job that needs to be done for yourself?
Where can non-consumption be seen?
Are there already work-arounds for certain problems?
What are the tasks nobody wants to do?
Are there already products that are used in different way then intended?
(Christensen et al., 2016, pp. 55 - 62)

Customer Segments

The *target customer* is the second of the nine elements and it is part of the second pillar, the customer interface (table 2). The *distribution channel* and the *customer relationship* element belong to the same pillar that covers all aspects related to customers. The customer interface describes how and to whom the company delivers the value proposition (Osterwalder, 2004, pp. 58-60).

Segmentation is important for the target customer element. If there is a good segmentation of customers it is much easier to use available resources and deliver the most attractive value propositions. According to Winter (1984), the idea of segmentation in marketing goes back to the 1950s (Osterwalder, 2004, p. 61).

Segmenting is essentially a separation of customers into subgroups. Each customer segment has different needs and preferences. The products and services can be better tailored to the customers' needs when the segments are known, but it is not always easy to divide the customers into subgroups. Segmentation may be hard to distinguish from demographics. Two female Austrian citizens, both of the same age, can have very different preferences and therefore buy different products or services (Gavett, 2014, pp. 1-3).

Some example business models for different degrees of segmentation are listed (Osterwalder & Pigneur, 2010, p. 21):

Mass Market A business model for the mass market does not distinguish between different segments. The focus is on one large customer segment with similar needs and the value propositions, distribution channel and customer relation blocks also just focus on this one group. This is a typical example in the customer electronics sector.

Niche Market This is the opposite of a mass market and the business model is only focusing on a very small, specialized customer segment. Such business models are often found in OEM markets where suppliers do not sell directly to end customers, an example being big car manufacturers purchasing their entire production.

Segmented There are business models that distinguish between different needs and problems of customers. An example is a credit company that offers other services and terms to customers depending on the volume of their assets, or a processor company that serves customers from the watch industry, the medical industry and computer industry.

Diversified A diversified business model tries to serve unrelated customer segments. For example, Amazon.com is selling cloud computing services because of its existing IT infrastructure needed for online warehouse business.

Multi-sided A classic multi sided business is a free newspaper where a lot of readers are attracting advertisers in order to generate revenue. Both sides are needed for the business model to work.

Channels

The third element of the business model onthology is the *channel* element. The channel element is one of the connections between the *value proposition* and the *customer segments*. The purpose of a distribution channel is describing how a company delivers value to the customers and to make sure that the right amounts of the right products are available at the right time in the right place. The constraints of a distribution channel are mostly costs and flexibility (Osterwalder, 2004, p. 63)

Because of the importance of channels they should be studied over the entire product life cycle. Therefore, channels can be divided into five phases and each channel can cover some or all of these phases (Osterwalder & Pigneur, 2010, p. 27):

Awareness In this first phase the customer recognizes that the value proposition could match their needs.

Evaluation After the customer is aware of the product or service, they want to know more about the solution that could solve their problem. The question is, if it is possible for the customer to easily access the information he may need.

Purchase In this phase the actual buying process is taking place. It should be possible for the customers to purchase solutions, including the negotiation, decision, contact, order and billing and the payment part of the transaction (Osterwalder, 2004, p. 67).

Delivery This phase is part of the purchase phase. But to outline the importance, how the customer gets the value delivered, it is mentioned for better understanding (Osterwalder & Pigneur, 2010, p. 27).

After Sales In this last phase it is possible to create loyal customers and build a customer base.

Furthermore, channels can be *direct* or *indirect* and a company can *own* them or *outsource* to partners. An own and direct channel would be a Web store, whereas an own but indirect channel would be a retail store. Partner Channels are always indirect. In figure 7 an overview about the initial phases from Osterwalder (2004) is presented. The *delivery* was originally included in the purchase phase, but mentioned separate in the later work (Osterwalder & Pigneur, 2010, p. 27).

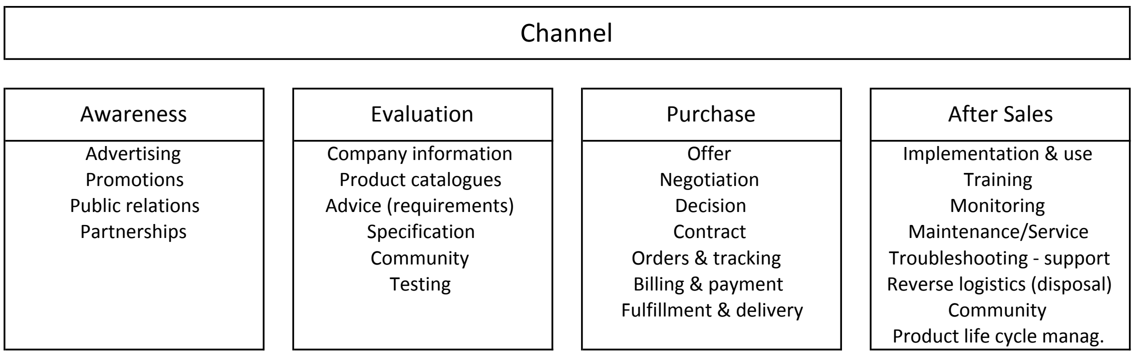


Figure 7: Phases of a Channel, adapted from (Osterwalder, 2004, p. 67)

Customer Relationships

The *customer relationship* is the fourth element of the business model onthology and it describes the relationship a company has with a customer segment. The goal for each company should be to fully profit of each customer relationship. To build a relationship it is necessary to interact with the clients and this interaction comes at a given cost. This is why it is important to know what customer is worth building a better relationship. Profits can be generated with *new customers*, the increase of *profitability of existing customers* or the *extension of the duration* that the relationship is going to last (Grant & Schlesinger, 1995, p. 60).

The relationships range from personal to automated and are driven by the motivation of customer acquisition, customer retention and the boosting of sales. The *customer relationship* is the missing link between *value proposition* and *customer segments* that is not covered by *channels*. Different categories of relationships can co-exist within a company (Osterwalder & Pigneur, 2010, p. 29):

Personal assistance Human interaction is the key in this type of customer relationship. During the purchasing phase the customer may be assisted to the end of the process by a customer representative. An advanced form would be a dedicated personal assistance where a customer has always the same representative. The private banking sector serves as an example when dealing with high net worth customers.

Self-service No direct contact with customers is happening and all the information a customer needs is provided for self study in this type of relationship.

Automated services This is an upgrade of self-service with some automated processes. Personal online profiles are an example and can help to build a more individualized service for customers. Automated services could simulate a personal relationship.

Communities To build up a community where customers can help each others can also be a cost efficient way to bring more services and knowledge to customers without dedicating more finances for customer relationships.

Key Resources

In this fifth element of the business model ontology it is about the capabilities of a company and these are resource dependent. There are a few categories for the *key resources* (Osterwalder & Pigneur, 2010, p. 35):

Tangible Most of the time these traditional resources appear on a firms balance sheet. They are the most conventional like buildings, vehicles, machines and distribution networks. Big retailers like Amazon.com or Wal-Mart often rely on capital intensive physical assets like a store network or infrastructure for logistics.

Intangible This category of resources has become more important in the last years and can also be seen as intellectual property which is hard to put on a balance sheet. Some intangible resources are partnerships, patents and copyright, brands and proprietary knowledge. It is hard to develop intellectual property but it can be very substantial within a company. Nike for example heavily relies on the brand it created and one of Nespresso's key resource were the patents they were holding.

Human Most companies need human resources but in some certain businesses people are more important, such as in creative and knowledge-intensive industries for example.

Financial Some business models work if there is a financial guarantee, for example cash or a stock option. A financial resource commonly is a tangible one, but in this case it is listed separately (Osterwalder & Pigneur, 2010, p. 35).

Key Activities

The *key activities* block describes what a company actually has to do. In this sixth element, a firm has to answer the questions of which key activities it has to perform in order to offer or create value propositions, reach markets through channels, improve customer relationships and generate a revenue (Osterwalder & Pigneur, 2010, p. 37).

Osterwalder uses the *value chain framework* from Porter (2001). In the value chain the main activities include logistics, operations, marketing and sales, and service. The value chain basically transforms input into the value proposition (Osterwalder, 2004, p. 84).

Furthermore, activites can be *primary*, or *supportive*. The primary activities create the value and include marketing and delivery. The supportive activities include infrastructure, human resource management, development and procurement (Osterwalder, 2004, p. 85). For simplicity activities can be categorized as follows (Osterwalder & Pigneur, 2010, p. 37):

Production This is the dominating activity for manufacturing companies. The production includes designing, manufacturing and delivering a product.

Problem solving Key activities related to problem solving are found in consultancies, hospitals and other service organizations. In these companies it is important to have activities like knowledge training and continuous training.

Platform / Network If there is a platform as a key resource, then most of the key activities are platform related.

Key Partnerships

The *partnership* element is the seventh element in the business model ontology. A partnership or alliance can be essential in a company's strategy, and according to Osterwalder the partnerships of today have changed in nature. The concept of joint ventures to reach new geographical markets has changed for strategic alliances to enhance the competitive position. So called value networks are defined as cooperative agreements between companies that are voluntarily initiated. The partnership includes exchange, sharing or cooperative development, and it can include the contribution of capital, technology or other assets (Osterwalder, 2004, p. 89).

It can be distinguished between three different types of partnerships (Osterwalder & Pigneur, 2010, p. 39):

Optimization and economy of scale This is a classic buyer-supplier relationship that should allow optimized allocation of resources and activities. For an enterprise it is not logical to perform every activity by itself or own every resource that is needed. Usually the benefit of optimization and economy of scale partnerships is a cost-reduction that often involves outsourcing or sharing of infrastructure.

Reduction of risk and uncertainty There is always some uncertainty involved in business and a partnership of competitors can help to reduce that risk.

Acquisition of particular resources and activities A partnership can be a good way to get deeper knowledge in one direction without spending on research. It can also be beneficial in manufacturing processes to gain knowledge. For example a phone manufacturer is licensing its operating system to let others develop applications for it.

Revenue Streams

This is the eighth element in the business model ontology and it describes the ability of a company to generate a *revenue stream* from the *value proposition* it offers to the *customer segments*. For a company it is possible to have more then one revenue stream and each of them can have a different pricing mechanism (Osterwalder, 2004, p. 96).

There are commonly two different models. The transaction revenue from **one-time payments** and **recurring payments** to keep a value upright. A revenue stream can be divided into different types (Osterwalder & Pigneur, 2010, pp. 31-32):

Asset sales The revenue stream is generated from selling ownership of a good or service for money. Amazon.com is selling books, as Fiat is selling automobiles. The buyer is free to use, resell or even destroy it. After a book is sold it is not possible to generate further revenue from it.

Usage fee If a customer uses a particular product or service and a company is charging for usage this revenue stream is generated. A hotel for example charges people for the number of nights a room is used. Another example is a telecom operator who charges for the minutes a phone call lasts.

Subscription fee If a continuous access to a service is needed, a subscription fee is also generating revenue. A gym for example sells its members monthy, yearly, or even hourly and in exchange people are allowed to work out at the facilities.

Lending If a company is giving away something for a period of time and is expecting to get it back this is called lending and can generate a revenue stream. The difference to licensing is that the product can not be used otherwise while lent. A bank for example lends money and while the money is lent it cannot generate further revenue from it.

Licensing To offer intellectual property can generate a revenue stream by giving customers the permission to use it in exchange for licensing fees. A big advantage of licensing is that a company does not need to manufacture a product or offer a service to earn money. In the media industry a lot of money is earned with licensing. A licensing fee could also give access to patented technology.

Brokerage fees If a business transaction is done between two or more parties and products or services are exchanged then a revenue stream for intermediation services can be generated. These transactional costs are the main revenue stream for software platforms that bring together buyer and seller in order to complete their business activity. Credit card providers that take a percentage from the value at every sales transaction between customer and the company serve as another example.

Advertising When someone is praising a product in public, through TV, web, magazines etc. in order to influence the opinion of the customer, this is termed advertising. It can generate a revenue stream that results from fees for advertising a particular product or service. Traditionally advertising was used in the media and event industry but nowadays it is becoming more important in other markets, such as software development.

The pricing mechanism for each revenue stream can basically be *fixed* or *market related* (table 4).

It can make a big difference in the amount of revenues generated. A fixed price is a list price, but can be different for other product features, other customer segments or dependent on the volume. If a company has dynamic pricing, then this is market related and depends on the negotiation, the time of the purchase and economics based on supply and demand (Osterwalder, 2004, pp. 98 - 100).

Fixed Pricing predefined prices		**Dynamic Pricing** prices dependent on market conditions	
List Price	everyone pays the same price for the product or service	*Negotiation*	price can be negotiated and depends on negotiation skills
Product configuration	the price is related to the product configuration	*Yield management*	calculation of prices dependent on inventory, capacity and time of purchase
Customer segment	the customer segment is influencing the price	*Real-time-market*	price is dependent on economics based on demand and supply
Volume	the price is a function of the quantity	*Auctions*	competitive bidding determines the price outcome

Table 4: Different Pricing Mechanisms, adapted from Osterwalder (Osterwalder & Pigneur, 2010, p. 33)

Cost Structure

The ninth and last element of the business model canvas is the *cost structure* block that summarizes the description of all costs that are necessary to create and deliver value. Furthermore the cost structure sets a price on the assets and resources, the activities, the distribution channels and customer relationship that all cost the company money (Osterwalder, 2004, p. 101).

Of course costs should be minimized but there exist models where the cost structure is more important then the other elements of the business model. This is why it is useful to differentiate between a **cost-driven** and a **value-driven** business model. Costs can be fixed, variable or depending on scaling effect (Osterwalder & Pigneur, 2010, p. 41).

Cost-driven This very typical business model is focusing on keeping the costs as minimal as possible, resulting in a lean cost structure. The model builds around low price value propositions, extensive outsourcing and maximum automation.

Value-driven A company less focused on low costs, most of the time, is more concerned about value creation. Premium value propositions and individualized services are usually the characteristics of value-driven business models.

Fixed costs Concerning just the costs and not the business model this costs stay the same, despite the production volume or produced services. This costs include salaries, rents, and buildings for manufacturing. Manufacturing companies have a high proportion of fixed costs.

Variable cost Costs are changing with the amount of goods or services produced.

Economies of scale These are cost advantages when a company has a higher output. For example, a company buying raw materials in larger quantities can negotiate a better price.

Economies of scope This means the advantages it could have if there is a larger scope of operations. For example, if a large enterprise uses the same marketing activities or channels for several products.

How to use the Canvas

The nine building blocks are describing the business model canvas from figure 8. There are no further rules for the business model generation, just a few points to consider. It does not matter which block is considered a starting point. Each block should be precise but must not be detailed. For different ideas more then one canvas may be used and a business model should always be able to tell a story (Osterwalder & Pigneur, 2010, p. 50).

In *Business Model Generation* from Osterwalder & Pigneur there is plenty of information to help with someone's own business model, as well as different examples from well known companies and a explanation of different approaches as there is no such perfect business model.

In section 5.1, a business model developed at AMST Systemtechnik can be seen. It was clear beforehand that the new product, the NHT Chamber, will try to satisfy many different needs and therefore it is of uttermost importance to gain an overview about the product with the help of a business model first.

2.2.4 Disruptive Innovation

As mentioned in section 2.1.2, disruptive innovation describes the characteristics of a new product or service where a new business model is combined with existing technology. In *»What is disruptive Innovation?«* Christensen et al. (2015) give further explanation about the principles of

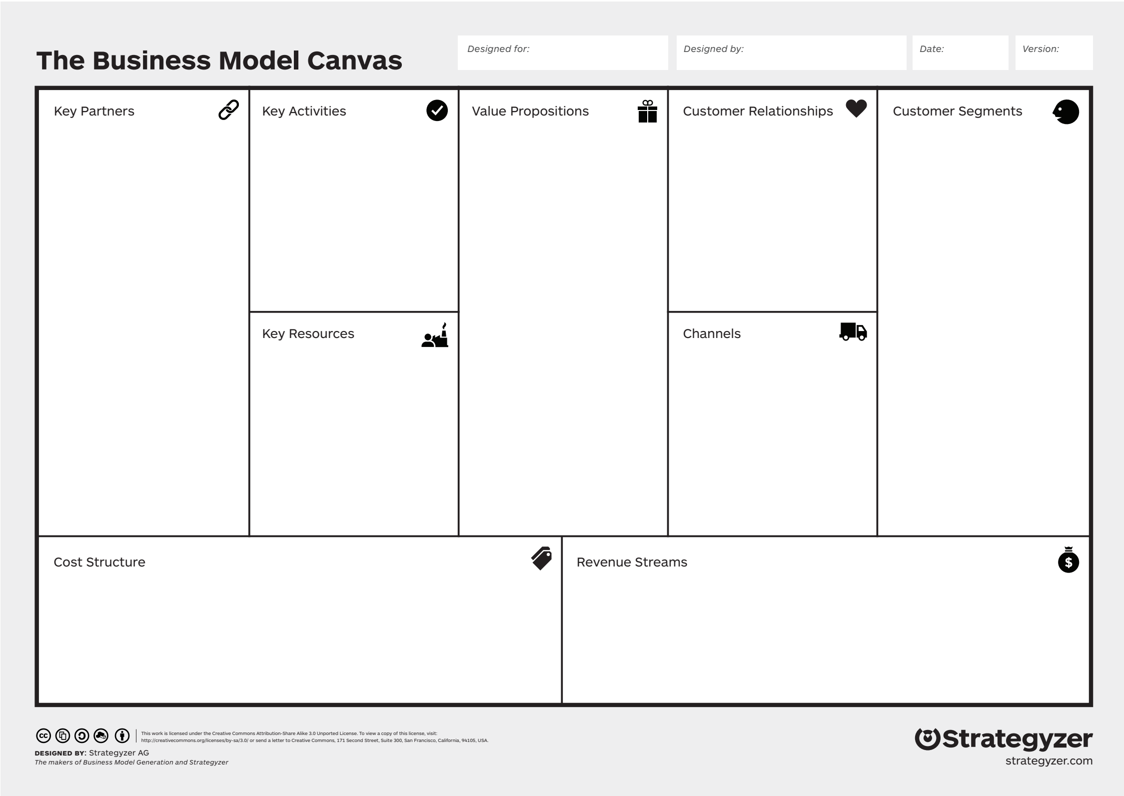


Figure 8: Business Model Canvas (Osterwalder, 2016)

disruption. In 1995 it was already proven that the theory of disruptive innovation works.

The success of the theory is a problem because it has been misunderstood and misinterpreted in the past which led to bad reputations. In addition some minor improvements have been made in the last 20 years that were not recognized because of the power of the initial formulation. The term "disruptive innovation" is also used too frequently by people when an industry is shaken up but no innovation is happening at all (Christensen et al., 2015, p. 45).

Disruptive Innovation Model

The term *Disruptive* describes it when a small company successfully challenges a established company. In particular, when an established company tries to improve its products or services for their most profitable customer, they ignore the needs of the smaller customer segments. When someone is focusing on the overlooked segments and targets them successfully, most of the time with lower prices, this is the start of disruption. The big and established company is not able and maybe also not be interested to act in the first place and the new company is able to deliver and is also able to gather mainstream customers with a continuous excellent service (Christensen et al., 2015, p. 46).

Figure 9 shows the disruptive innovation model with contrasts of product performance and customers' demands over time. The red lines represent the product improvement and the blue lines show the customers' demands, or willingness to pay. When established companies increase the performance of their product in order to serve the high end market but the willingness to pay is not climbing at the same rate, then a place in the less profitable segments for new entrants is generated. The entrants also start to move upwards, challenge the incumbents for higher profitability and in no time there will be a place for a new entrant or disrupter (Christensen et al., 2015, p. 47).

Figure 9: The Disruptive Innovation Model (Christensen et al., 2015, p. 49)

Essentials for Disruptive Innovation

If it is possible to recognize real disruptive innovation then this leads to tremendous advantage because it helps to disrupt and to understand other business models better. Christensen et al. have observed the overlooked or misunderstood points:

Disruption is a process and takes time. This is why disrupters frequently are overlooked by incumbents. Netflix for example started in 1997 with delivering movies through U.S. mail. They had a big movie database but did not have new releases and therefore served only a few customer groups. This is why the market leader, Blockbuster did not react because they served very different customer segments. Later, when Netflix started its online streaming service it was too late for Blockbuster to react. Netflix got there with a classic disruptive approach (Christensen et al., 2015, p. 49).

Disrupters often build different business models. Apple's iPhone is an example of using a innovative business model. The initial success was given due to superiority of the product against incumbents. Nonetheless its growth rate can be explained with disruption of the laptop as the primary way to access the Internet. The network that allowed an easy access to many applications from different independent developers was their newly created business model that led to success (Christensen et al., 2015, p. 50).

Not every disruption works. By definition, a disruption does not mean success and a company can also have success without a disruptive strategy. Examples are the large number of Internet-based retailers that tried disruptive paths but just a few of them prospered (Christensen et al., 2015, p. 50).

Disrupt, or be disrupted is not true. This means that incumbent companies should react if they recognize disruption, but they should not overreact if they are still running a profitable business (Christensen et al., 2015, p. 51).

There is still a lot more to learn about disruption and the theory has space for refinement (Christensen et al., 2015, p. 53). In the next section, a look at business models from a similar perspective with the principle of four dimensions of business models is taken.

2.3 Types of Business Models

Besides the business model canvas from Osterwalder & Pigneur, there exists another famous tool to describe a business model. Gassmann & Kobe (2006) are referring to the *four dimensions* of a business model which are used in the St. Galler Business Model Navigator™ . In this theory, the definition of a business model refers to it as a blueprint of how a company creates and captures value. In this section some example patterns of successful business from Osterwalder & Pigneur (2010) and Gassmann et al. (2013) are shown.

2.3.1 The Main Elements of Business Models

On the knowledge gained from cooperation with companies, a simple and holistic tool to describe business models was developed. This tool to describe a business model consists of four dimensions, which are displayed in the "magic triangle" in figure 10 (Gassmann & Kobe, 2006, p. 6). This approach is similar to the who, what and how from Markides (1999).

The Customer - who are the target customers? For a business model to be successful, a company needs to exactly understand who the relevant customers are that need to be addressed. According to Gassmann et al. (2013), the customer is always in the focus of every business model.

The Value Proposition - what is offered to the customer? The second dimension describes what is offered to the target customer in order to serve his needs. The value proposition describes the companies' solutions that are useful for the customer.

The Value Chain - how is the value proposition created? In order to create the value proposition, a company has to perform different activities and processes. In addition to these activities and processes, the capabilities and their coordination alongside the companies' value chain are shaping the third dimension of a business model.

The Revenue Mechanism - how is revenue created? The fourth dimension explains how a business model is financially sustainable. It includes the cost structure as well as the revenue streams. This dimension answers the central question of how to earn money.

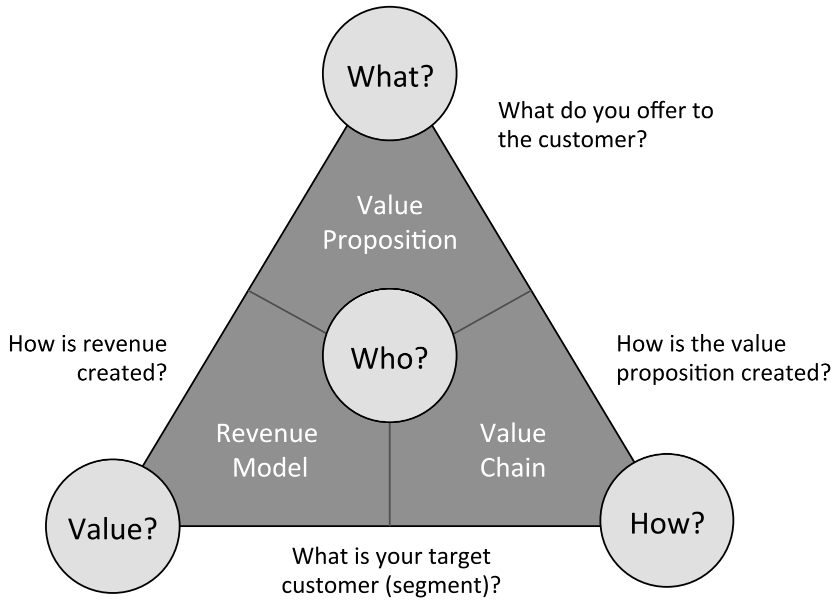


Figure 10: The magic triangle with the four dimensions of a business model, own translation (Gassmann et al., 2013, p. 6)

With the answers to these four questions, as well as the definition of the customer segments, value propositions, value chain and revenue mechanism, a business model becomes tangible and lays the foundation for innovation. It is called a "magic triangle" because optimization on one corner results in changes in the other corners. The assumption is that a business model innovation needs at least changes in two of the four elements (Gassmann et al., 2013, p. 7).

2.3.2 Samples of Business Model Innovations

At this point, selected samples of business models are explained. The examples are selected from the 55 innovative samples proposed by Gassmann et al. and have similarities with the patterns mentioned in Business Model Generation (Osterwalder & Pigneur, 2010, p. 55).

Auction This sample is focusing on the **what** and the **value**. The idea is to sell a product or service to the customer with the best bid. The final price is determined when the time is over or no higher offer is made. This enables the company to sell at the highest price the customer is willing to pay and the customer benefits from the ability to influence the price of the product. A classic example is eBay (Gassmann et al., 2013, p. 86). An auction is a pricing mechanism where the customer determines what he wants to pay (Osterwalder & Pigneur, 2010, p. 33).

Freemium The freemium sample is also concentrating on the **what** and the **value**. The basis version of the product is free to use and the customer needs to pay for premium features if they want to use the additional functionality. With the free version, a large customer group should be generated. The more customers that use the free version, the higher, in theory, is the probability that some of them will pay for the premium service. Examples are Skype, Spotify and Dropbox (Gassmann et al., 2013, p. 134). Only a small portion, usually less than ten percent of all customers, pay for premium services and this should be enough to subsidize the free users (Osterwalder & Pigneur, 2010, p. 96).

Lock-in This sample is focusing on innovation in two of the four dimensions: the **how** and the **value**. Customers are being locked-in the ecosystem of the company. A change to another firm would result in increased costs and should prevent the loss of customers. Lock-in is either generated with unique mechanisms or substantial dependencies on other products. This is also referred as the Razor and Blade pattern, and examples are: Gillette, Lego, Nestle Nespresso and Hewlett-Packard (Gassmann et al., 2013, p. 163). Osterwalder & Pigneur adds the example of todays telecommunication industry, that is offering cheap subsidized smartphones bundled with service subscriptions (Osterwalder & Pigneur, 2010, p. 105).

Long-Tail The innovation is happening in the dimensions **what**, **how** and **value**. A long tail strategy does not focus on a few products that are selling in large amounts, but on the generation of revenue with a large quantity of niche products. On their own, these products would not generate large revenues or sales figures. Due to of the high number of different products, the small revenues can total in large numbers (Gassmann et al., 2013, p. 167). Three economic triggers gave rise to the long-tail phenomenon in the media industry: democratization of tools of production, democratization of distribution and falling search costs to connect supply with demand. Examples are Amazon and Lego (Osterwalder & Pigneur, 2010, p. 66).

Rent Instead of Buy is focusing on the **what** and **value**. With this pattern a product is not bought by the customer, but it is rented. Due to the reduction of acquisition cost a customer can afford previous unaffordable products. Furthermore, a constant revenue stream can be generated. Examples are Xerox, Rent a Bike or Car2Go (Gassmann et al., 2013, p. 206). And furthermore, Hilti, moved away from selling tools toward renting sets of tools to customers (Osterwalder & Pigneur, 2010, p. 139).

Solution Provider A solution provider is concentrating on the **what**, **how** and the **value**. Companies offer their customers not just products, but solutions with integrated products and services. As the firm is covering the whole problem, it serves as the single point of contact to the customer. The close connection can further be used to gather information about the preferred usage and additional needs in order to optimize the services. A classic example is Apple with its iPod/iTunes integration (Gassmann et al., 2013, p. 228).

Multi-sided Market This sample focuses on innovation in three dimensions: the **who**, **what** and **how**. Two-sided markets enable the interaction between two or more distinct but independent group of customers. The more customers that are in one segment, the more attractive it is for other segments to get in contact with them and vice versa. Examples are eBay, Metro Newspaper, Google, Facebook, MyHammer and Groupon (Gassmann et al., 2013, p. 244). Another example is a video game console with the buyers on the one side and the developers on the other. The problem is, as if there are not enough buyers, the developers are not willing to support their product through the video game console. On the other hand, the buyers are not attracted to the console if there are not many games available at the start. Osterwalder & Pigneur are talking about a "chicken and egg" dilemma (Osterwalder & Pigneur, 2010, p. 78).

The business model case of the NHT fits in the solution provider pattern. AMST is creating value for customers with a professional high-altitude training system and is not just offering the product, but also the knowledge for training and the support for the training equipment, in order to be the only contact for altitude training that the customer needs.

From these seven examples, the diversity of business models can be seen. For an additional 48 samples, the book from Gassmann et al. is recommended. The next chapter will continue with an introduction to product development and how to implement a modularization concept to use scaling effects and partition the development costs.

3 Introduction to Product Development

The term *product development* describes the professional activities that need to be performed in order to solve a technical problem and bring the solution to market (Feldhusen & Grote, 2013b, p. 10). Product development is a complete process that includes research and development as well as computer aided design in order to transform a market opportunity into a available product that can be sold (Krishnan & Ulrich, 2001, p. 1).

In this chapter the product development process is briefly explained and information about modular product development is provided.

3.1 The Product Development Process

Due to the complexity of most products it is impossible to develop them in one single step. Rather, the product development happens in many small steps that have a defined content and interface description. The sequence of the work steps during product development is called **product development process** (Feldhusen & Grote, 2013a, p.11).

3.1.1 The Development and Design Guideline

The work-steps that lead from the product idea to the generation of the manufacturing documents are summarized under the term **development and design process** (Feldhusen & Grote, 2013a, p. 13).

The complexity of the product has a big influence on the development and design process. Therefore it was important to bring together methods that help build a target-oriented process that can be followed (Feldhusen & Grote, 2013a, p. 14).

VDI-2221 (1993) is a unique combination of early process models that were either valid for development or design. Figure 11 shows that usually more than one iteration is necessary. The first results always need improvements and corrections and the *iterative towards and backwards between stages* shows the necessary control process as a part of the guideline for development and design. After results are present they should be checked immediately regarding fulfillment of their requirements (Feldhusen & Grote, 2013a, p. 16).

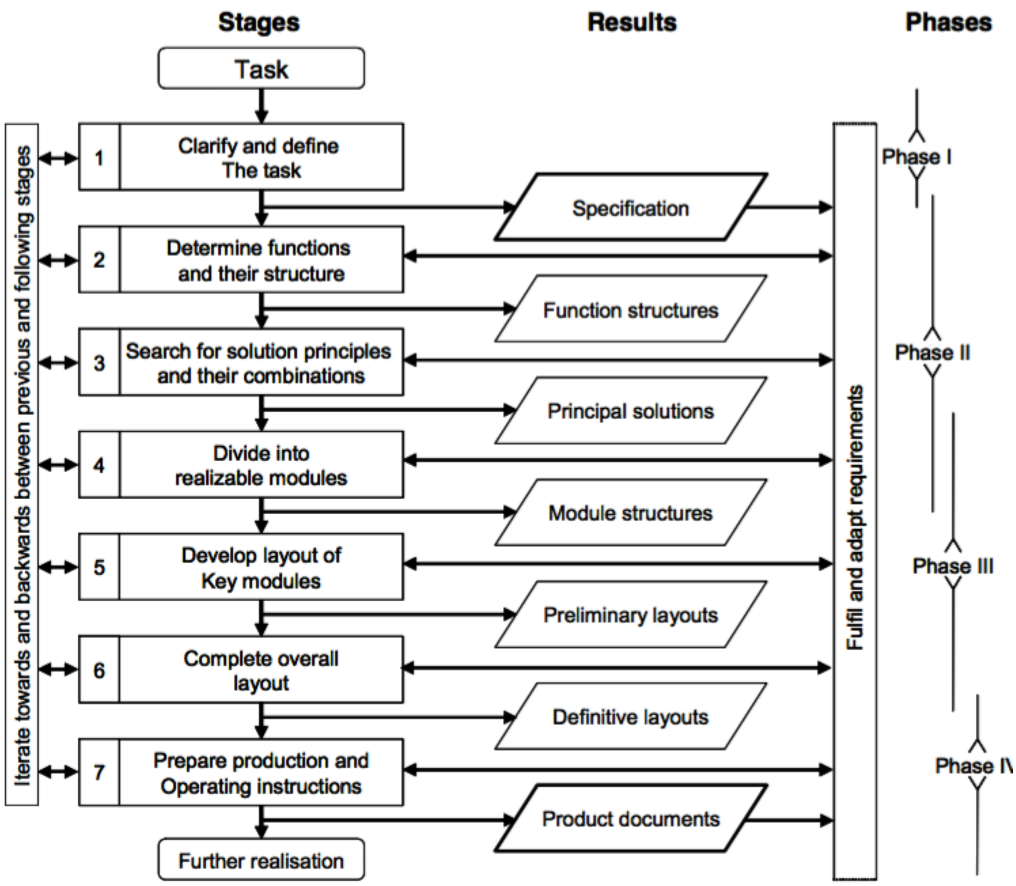


Figure 11: Guideline for Development and Design (VDI-2221, 1993, p. 9)

In the early 90s, the guideline for development and design was the standard process in the software development and was also used in mechanical engineering. The VDI-2206 (2004) is shown in figure 12. It is also called the V-model and was developed for mechatronic systems. The *assurance of properties* is similar to the control process from VDI-2221 (1993) and guarantees a short control loop (Feldhusen & Grote, 2013a, p. 18).

In addition, Feldhusen & Grote states that an engineering design can only be as good as the framework conditions allow. Due to economic considerations, product development cannot always

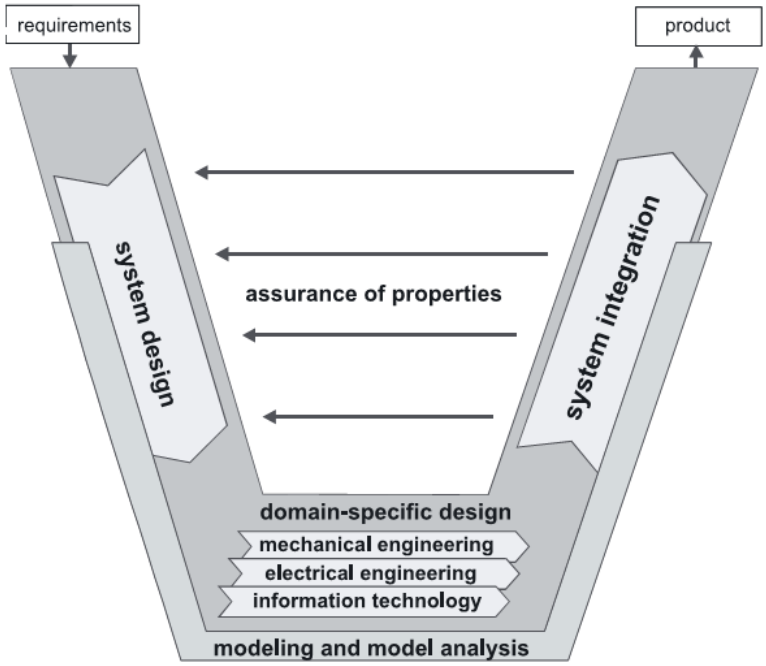


Figure 12: V-model as a Macro Cycle for Mechatronic Systems (VDI-2206, 2004)

lead to a perfect design from a technological view (Feldhusen & Grote, 2013a, p. 19).

3.1.2 The Steps of the Product Development Process

Feldhusen & Grote divide the product development process in different phases that are seen in figure 13 (Feldhusen & Grote, 2013a, p. 22). The first phase is devoted to **planning**.

Figure 13: Product Development Process, own translation (Feldhusen & Grote, 2013a, p. 23)

Second, **research and development** that follows the main steps: finding the solution, evaluating the solution and selecting the solution.

Concept development is the third phase and follows the steps: determination of preliminary product architecture, determination of main parameters such as functions, cost, interfaces, electrics and software.

The fourth phase is the **concept design** with the main steps: determination of product structure, determination of parameter from the main assemblies such as space and weight, and development of a manufacturing concept.

In the fifth phase, the **design** is determined with the main steps: structure main assemblies into parts, design of the parts and design of interfaces between parts.

The sixth phase is the **documentation** phase, including manufacturing documents, application documents, maintenance documents, repair documents, recycle documents and more documents about work safety.

In small and medium-sized companies the step of *product planning* is often neglected. The products are developed because of occasional random product ideas. This process can be successful if the responsible people have the right ideas (Feldhusen et al., 2013b, p. 301).

Many companies try to implement the product planning as a process in order to sustain corporate success. Product planning is also influencing the degree of innovation because it is directly connected with the company's strategy. Besides management, there are different divisions like marketing, research and development, and sales involved. To be successful with a product it is of central importance to include the customers' requirements in every phase of product development. To translate the customer requirements into functional requirements it is common to use the QFD method. The QFD is mostly used to redesign existing products but is limiting the creativity when creating a new product where the customer requirements are not really known (Feldhusen et al., 2013b, pp. 302).

The product development process is initiated with some kind of assignment. In general the task is formulated from product planning as a development contract or from the sales department as a specific order. In this first phase of the **product development**, the product's specifications need to be detailed (Feldhusen et al., 2013b, pp. 319).

With the **concept development**, the functions of the product need to be defined. The function carriers help to translate them into technical requirements. The concept should display the product architecture, with the principle of the assemblies and if necessary, the sub-assemblies. The concept development is of highest importance because it is very hard to remove a mistake that occurred during the concept phase (Feldhusen et al., 2013b, p. 341).

During the product development process, multiple solutions for the problem can be developed. The **selection and assessment** is the last step that needs to be done in order to define the further steps in the product life cycle (Feldhusen et al., 2013b, p. 380).

Ideas to Simplify the Development Process

In order to withstand the global competition, a company's product needs to be sold at a certain market price. In high-wage countries the development costs take a huge part in the product development process and therefore need to be minimized without changing the products quality. Furthermore the customer expects to have a product that meets his needs and therefore the company has to offer different product variants. Due to market limitations however, an increase of product variants means there is only a finite number of products of the same variant which can be sold. To deal with different variants *design series*, *modular designs* or *modular structured products* are used (Feldhusen et al., 2013a, pp. 769 - 770).

In the VDI-2221 (figure 11), the division in modules is required after the solution principles have been found. The module structure describes the schemata between the product structure and their different functions (Ulrich, 1995, p. 419). A modular product architecture is the opposite to a integrated product architecture and has the benefit of relative functional and physical independent components (Göpfert, 1998, p. 91). In order to gain further insight into modular product structures, a description consequently follows this section.

3.2 Modular Product Structure

Within recent years, industrial competition has become even stronger and customers wish low prices as well as individual products. With modular systems it is possible to meet these contradictory customer requirements (Krause, 2012, p. 659). It is a challenge for product development to generate a variety of products while keeping the costs low. If the *reduction of complexity* leads to *cost savings* without *reducing product range*, this is referred to as **Design for Variety** (figure 14).

Modularization in product development reduces customer-related development with the configuration of predefined modules. This results in a cost reduction because the modules can be used repeatedly and in higher quantity (Kipp & Krause, 2008, p. 425). In this section, basic concepts of modular product architecture are explained.

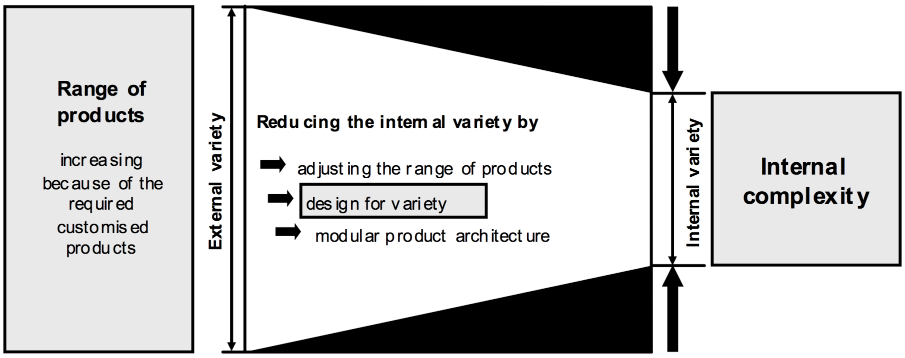


Figure 14: Design for Variety (Kipp & Krause, 2008, p. 425)

3.2.1 Forms of Product Structure

The structure of a product can be defined with functional elements or physical components. In figure 15 the *structure of the functions* are opposed to the *product structure*. The collective of functional and physical descriptions is called *product architecture* (Ulrich, 1995, p. 419). In contrast to product architecture, the product structure refers on the physical components only (Schuh et al., 2014, p. 122).

In most literature product structure and product architecture are used as synonyms without differentiation. The definition of product structure determines the production characteristics, the quality control and assembly process (Krause, 2012, p. 660). In product development usually the functions are defined and translated into the product structure (Göpfert, 1998, p. 75). In this section the common forms of product structures are explained.

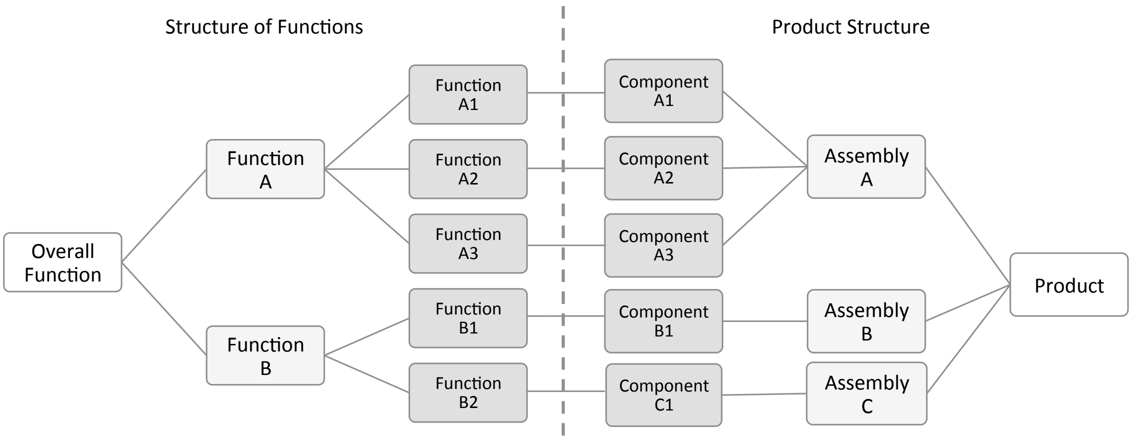


Figure 15: Scheme of a Product Architecture, own translation (Krause, 2012, p. 661)

Differential and Integral Design

The combination of single parts into one component is called *integral design*. On the other hand, *differential design* describes the dissection of a component with many functions into smaller components with less functions (fig. 16) (Ehrlenspiel & Meerkamm, 2013, p. 499). Advantages of differential design include the usage of standard parts or the reduced dimensions and complexity of parts for assembly. Integral design benefits of less connections between parts and fewer assembly steps.

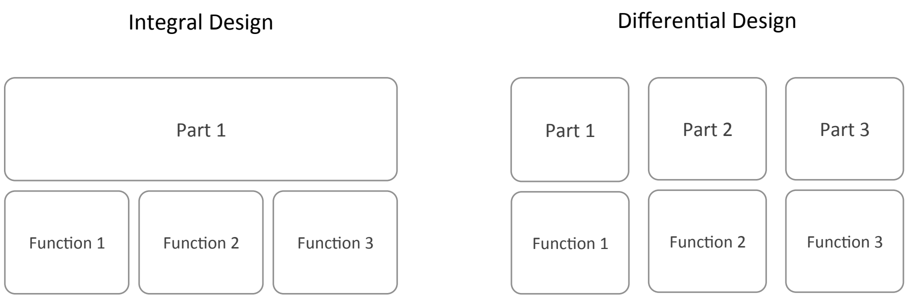


Figure 16: Schemata of Integral and Differential Design, own translation (Krause, 2012, p. 661)

Design Series

Design series are parts with identical functions and a systematic scaling parameter. This parameter can be of physical nature (performance, speed, force), describe a measurement (length, width, diameter) or material related. The step range is primarily based on geometrical series, with a constant ratio between successive terms. Humans find that kind of scaling more attractive than an arithmetic series fixed steps. A series has the advantages of reduced design effort and higher quantities for fewer variants. On the other side, the product is not individually fitted and may be oversized (Krause, 2012, p. 662).

Modular Design

The modular design approach combines functions of a system into smaller parts called modules. For the modules to work together, the use of industry standards for interfaces is highly recommended. A advantage of modular design is the easy repairability with exchangeable modules and a disadvantage is the higher engineering effort due to additional interfaces. Modular design serves as the base for modular product structures (Krause, 2012, p. 662).

Modular Structured Products

In literature many definitions for modular structured products exist (Ulrich, 1995; Erixon, 1996; Göpfert, 1998; Salvador, 2007). A solid approach to sum up the definitions from engineering and economics of modular products includes these characteristics (Salvador, 2007, p. 222):

Component communality Modules are used in several positions within the product family.

Component combinability Products can be configured with the combination of a modules respective components.

Function binding There is a fixed assignment between functions and modules.

Interface standardization The interfaces to connect the modules are standardized.

Loose coupling Interactions of the components within a module are stronger then interactions of the components of different modules.

In figure 17 a sketch shows these five characteristics of modular structured products. The degree of modularity needs coordination with the corporate strategy. Therefore the aim of modular design is to meet a suitable degree of modularity (Krause, 2012, p. 663). Hereafter the potentials and the limits of modular product families follow.

3.2.2 Potential and Limits of Modular Products

A modular product architecture benefits all across the product life cycle because of the functional and physical separation of the components. The potentials are shown in figure 18. This seclusion results in a product that is very robust against changes in design. The modules are mainly independent and therefore changes in one module do not influence the other components. For example, it is possible to change a module within the product life cycle in order to adapt to new manufacturing technology or legal regulations without changing the rest of the product (Krause, 2012, p. 664).

During **product development** different modules can be *reused* which consequently *reduces the complexity*. The clear product structure helps to divide work packages across the organization and the modules can be *developed simultaneously*. The seclusion also lowers the *documentation* effort. The **purchasing** can benefit from *pre-assembled modules* that have already been *tested* by the supplier. It is also possible to *outsource* the whole development process to a supplier.
Similar to the development the **manufacturing** process can benefit from *reused* modules. Due to

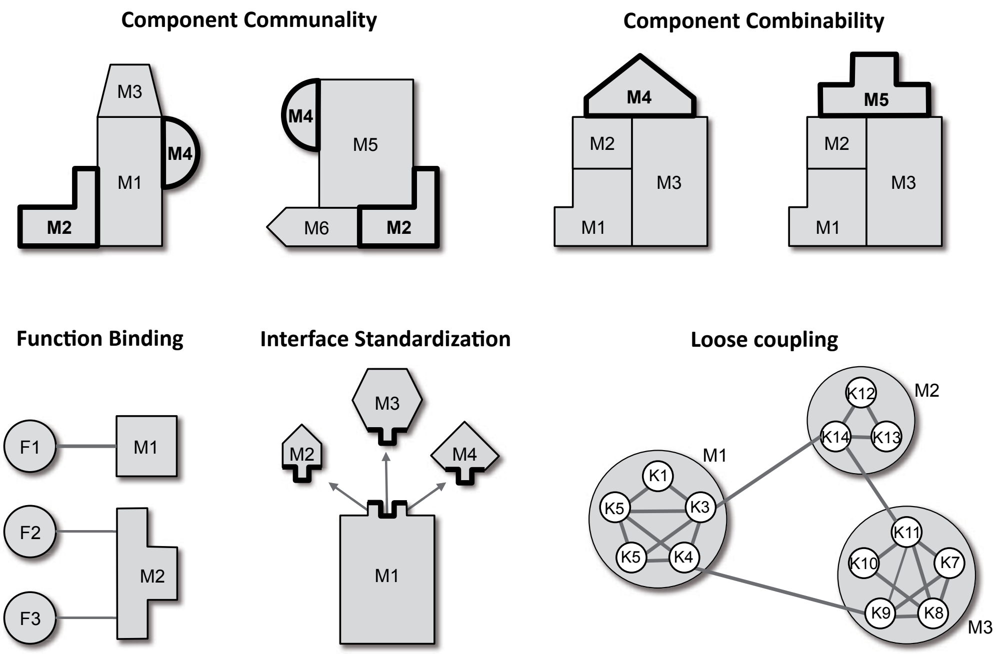


Figure 17: Characteristics of Modular Products (F = Function, M = Module, C = Component) own translation (Krause, 2012, p. 663)

the higher quantities the company benefits from *economies of scale* and *learning curve effects*. Furthermore, simultaneous manufacturing of different modules allows *separate testing* and *quality control* and this helps to find defect modules faster.
In **sales** it is easier to adapt to the customer requirements due to different *product variants* and configurations.
During its **usage**, the product can be easily *upgraded* with modules of additional functionalities. Customers also benefit from the ability to *exchange* defect modules.
In the **recycling** phase of the product life cycle there is also potential to *reuse the modules for new products* and in general, modules are *easier to recycle* than the whole product.

On the contrary, there are also **limitations** of modular products. The modular product architecture can have a huge impact on the optimization of the overall product. Because the same modules are being used in different product families, most of the time they are *oversized* compared to their actual needs and cannot be optimized for the intended product.

Furthermore, modular structured products need certain *interfaces* where there is no need for integrated products. In general this means a bigger mass, more space and a higher engineering effort. Integral products are the first choice if space and mass are very critical for the product. The

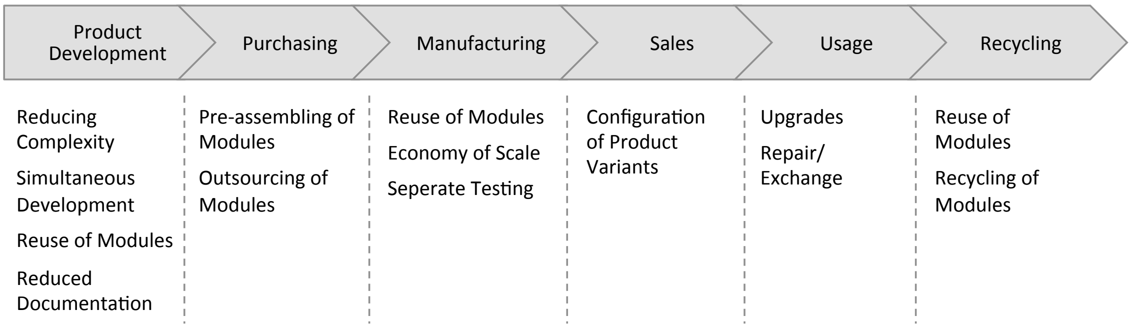


Figure 18: Potentials of Modular Products During Life Cycle, own translation (Krause, 2012, p. 665)

same is true for simple products with large quantities (Krause, 2012, p. 665).

3.2.3 Methods for Modular Product Development

There are different methods to develop modular products, but the *Integration Analysis Methodology* from Pimmler & Eppinger and the *Modular Function Deployment* from Erixon are of particular importance. The one is a more technical-functional based method and the other focuses more on strategic factors (Krause, 2012, p. 665). In this section the two models are explained one is used for the NHT development.

Integration Analysis Methodology

In this method the Design Structure Matrix (DSM) is used to gather components considering their functional relations (Pimmler & Eppinger, 1994, p. 3). The method is divided into three steps.

In the first step the product is **decomposed into elements**. It is important if the elements are just functions or already components of the product. The degree of decomposition should be one increment more detailed than the aspired detail of product architecture.

To **document the interactions between the elements**, the elements are put into DSM. Now they are assessed in different categories of interaction. The four categories are *spatial*, *energy*, *information* and *material*. Each category is assessed with a scale from -2 (unhealthy relation) to -1 (undesired relation), 0 (neutral) and 1 (desired relation) to 2 (necessary relation).

		A	B	C	D	E	F	G	H
Element 1	A		0 0 0 2	0 1 1 0				1 2 -2 1	
Element 2	B	0 0 0 2			2 2 0 0	2 -1 1 -2			1 2 0 -1
Element 3	C	0 1 1 0				2 1 -1 0			
Element 4	D		2 2 0 0			-2 -1 0 0	2 0 1 -1		
Element 5	E		2 -1 1 -2	2 1 -1 0	-2 -1 0 0		2 0 1 1		
Element 6	F				2 0 1 -1	2 0 1 1		0 2 1 -1	
Element 7	G	1 2 -2 1					0 2 1 -1		2 -1 -1 -1
Element 8	H		1 2 0 -1					2 -1 -1 -1	

Spatial	S	E	Energy
Information	I	M	Material

Figure 19: Design Structure Matrix, adapted from Pimmler & Eppinger (1994)

In the third step the elements are **clustered into chunks** like in figure 19. Therefore, the matrix is reorganized in order to bring the positive relations closer to the diagonal line and the potential modules can be identified (Blees et al., 2008, p. 150). This technical-functional based approach can be computer-aided and therefore has the possibility to be used for very complex problems.

Modular Function Deployment (MFD)

In the MFD products are being unitized by considering strategic aspects. MFD consists of five steps (Erixon, 1998, p. 65) like displayed in figure 20.

As in every product development process the first step is to take a look at the **customer requirements** in order to ensure the right design requirements are defined. Erixon is referring to the application of QFD in a multi-disciplinary team being well suited for that task. It is recommended to put "modularity" into the first design requirement of the QFD in order to get the right direction for each of the design members (figure 21). This results in modularity being assessed against the customer needs at an early stage where it can be seen if the modular design aids the fulfillment (Erixon, 1998, p. 66).

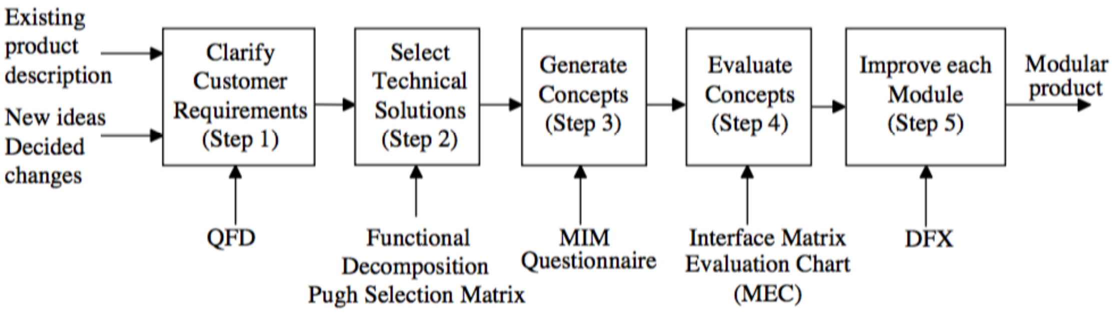


Figure 20: Module Function Deployment (MFD) (Erixon, 1998, p. 65)

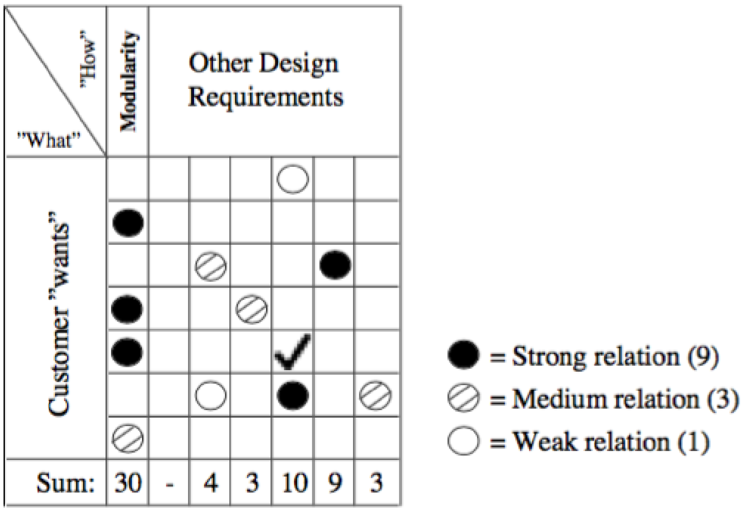


Figure 21: QFD with Modularity as the First Design Requirement (Erixon, 1998, p. 67)

In the second step, the **technical solutions** are selected. For this purpose the product is separated into functions and sub-functions; so called function carriers. Each function can be represented by a technical solution (Krause, 2012, p. 670). Good modular designs are robust, which means that the modules have very little interactions between themselves. This can be achieved with independence between different functions and technical solutions (Erixon, 1998, p. 69).

The main modularization happens in the third step, the **concept generation** with the use of the Module Indication Matrix (MIM) in which the function carriers are assessed one by one against each module driver (Krause, 2012, p. 670). Twelve module drivers have been found in case studies to be the main force behind modularization alongside the product life cycle (Erixon, 1998, pp. 72-77).

- A driver for *carry-over* describes a part or module that can be carried over from an earlier

Module Driver	Function Carrier	Sub-Function 1	Sub-Function 2	Sub-Function 3	Sub-Function 4	Sub-Function 5	Sub-Function 6	Sub-Function 7	Sub-Function 8	Sub-Function 9	Sub-Function 10
Development and Design	Carry-over	●				○		●	●		
	Technology push						◑			◑	◑
	Production planning				◑		●				
Variance	Technical specification			○							
	Styling	●						◑	◑		◑
Production	Common unit				●			○			
	Process/Organization										
Quality	Seperate testing		●								◑
Purchasing	Black-Box engineering				◑	○		◑		○	
After sales	Service and maintenance		◑				●		◑		
	Upgrading				●						
	Recycling					●					○
● 9 ◑ 3	Weight of Driver vertically summarised	18	12	1	24	11	21	16	15	4	10
○ 1	Module candidates	✓			✓		✓				

Figure 22: Module Indication Matrix (MIM) adapted from Erixon (Erixon, 1998, p. 78)

generation and reused in a new product generation.

- The *technology evolution* driver refers to a sub-system or part that is likely to be changed during the product life cycle because expected changes in customer demands or evolution of technology.
- The *production planning* phase is crucial for the product's success and this driver describes if planned changes are going to happen at a specific time.
- A *technical specifications* driver describes if variants of one or more parts of the product exist. It is important to keep the number of variants and sub-systems at a minimum in order to save costs on inventory and customer service.
- A *styling* module can be useful if the product is very sensible on trends and fashion. This has the advantage that design changes are not influencing the other modules.

- *Common units* are parts or sub-functions that are similar for different product variants. Even if there is a high degree of variation between products it is a good idea to use common units when the basic functions of sub components are the same.

- For different modules it is possible to have similar *processes* and *organizations* involved. This offers the ability to improve shop floor organization and employee satisfaction.

- *Separate testing* is a driver because components can be tested before they are assembled. This improves the quality and reduces the feedback time.

- *Black-box engineering* reduces purchasing and saves costs. This driver describes the usage of standard modules, bought from specialists instead of individual parts that need their own engineering effort.

- Another module driver is related to *service and maintenance*. With an exchange of defect modules the service times are improving tremendously. The broken module is repaired afterwards in order to exchange the next broken module with it.

- If necessary, modules can be changed or *upgraded*. This is easier than upgrading the whole product.

- The limitation of different materials in each module can improve the degree of *recycling*.

Every sub function is rated with a scale for each driver from 0 (= no driver), 1 (= weak driver), 3 (= medium driver) and 9 (= strong driver). This scale for weighing is adopted from QFD. The points of components are being summarized vertically as in figure 22. A high sum indicates a module candidate. This module candidate can be supplemented with a component that has a lower value and a similar profile. It however makes no sense for example to combine a component with a strong carry-over driver and a strong technology push component (Krause, 2012, pp. 670-671).

In the fourth step, the concepts developed with MIM are evaluated. This includes a detailed view of the interfaces between the modules and other evaluations normally done in development, production and after-sales. After the evaluation the last step covers the development of the modules. This step is not detailed in MFD. Modular Function Deployment offers a easy to use and very applicable method. Due to the module carriers, it pays more attention to the strategic reasons than to the technical and functional aspects (Krause, 2012, 671). In section 5.1 the MFD is used in order to help with the concept of the configuration file. Before the concept for NHT is developed the theory of high-altitude training is detailed below.

4 High-Altitude Training

The term *high-altitude training* describes a physical activity performed in atmospheric hypoxia, which naturally occurs at high altitudes, in order to increase performance. This can include endurance, strength, respiratory muscle training or simply therapeutic and regeneration training. According to dictionary.com (2015) hypoxia means *»a deficiency in the amount of oxygen delivered to the body tissues.«*

In this chapter, the atmosphere with certain amounts of gases is calculated and the heights are classified. Then an overview about the simulation of altitude is given and finally the effects of altitude training are expressed.

4.1 The Atmosphere

The beginning of the atmosphere dates back four billion years. Todays oxygen amount with a fraction of inspired oxygen (FiO_2) around 0,21 at sea level first occurred 350 millions years. There have been some fluctuations in the oxygen (O_2) content since then. The process of photosynthesis is the only reason why the atmosphere is sustainable today. Green plants disassemble carbon dioxide (CO_2) from the air, use the carbon part for their cell structure and emit oxygen to the atmosphere because they cannot use it. The main parts in the atmospheric gas composition today are oxygen with 20,95 %, nitrogen (N_2) with 78,08 % and 1% argon as well as a negligible amount of noble gases (neon, krypton, xeon) and some others listed in table 5. The relative amount of gases stays the same up to 11.000 meters of altitude. This means the percentage of O_2 stays the same, but the absolute amount decreases (Domej & Schwaberger, 2015b, p. 290).

4.1.1 Height Classification

According to agreements geographical heights are classified into moderate (1500 - 3000 m), high (3000 - 5500 m) and extreme altitude (above 5500 m) (Berghold & Schaffert, 2010). A more

Component	Fraction in %
Nitrogen (N_2)	78,08
Oxygen (O_2)	20,95
Argon (Ar)	0,93
Carbon dioxide (CO_2)	0,034
Neon (Ne)	0,0018
Helium (He)	0,0005
Methan (CH_4)	0,00016
Krypton (Kr)	0,00011
Hydrogen (H_2)	0,00005
Carbon monoxide (CO)	0,00002
Ozon (O_3)	0,000007
Xenon (Xe)	0,000003

Table 5: Components of Atmospheric Air, own translation (Domej & Schwaberger, 2015b, p. 291)

detailed classification, with amounts of oxygen in relation to sea level is found in an article from Sinex & Chapman. In table 6 the classification is listed with near sea level, low, moderate, high and extreme altitude.

Near sea-level, or up to 500 meters does not result in any changes at all. At *low altitude*, from 500 to 2000 meters, there is still very little decrease in aerobic performance detectable. Mountain sickness can start to occur at *moderate altitude* and acclimatization gets increasingly important for performance in the 2000 to 3000 meters range. At *high altitude*, from 3000 up to 5500 meters, it is still possible to live with acclimatization, but this is also where the most severe form of mountain sickness occurs and a significant decrease in aerobic performance happens. At extreme heights, classified as 5500 meters and above, no permanent residence is possible and symptoms get worse with the duration of exposure (Bärtsch et al., 2008, p. 96).

Classification	Altitude (m)	Equivalent FiO_2 (%)
Near sea-level	< 500	19,8 - 20,95
Low altitude	500 - 2000	16,7 - 19,8
Moderate altitude	2000 - 3000	14,8 - 16,7
High altitude	3000 - 5500	10,9 - 14,8
Extreme altitude	> 5500	< 10,9

Table 6: Classification of Altitude, adapted from (Sinex & Chapman, 2015, p. 325)

4.1.2 Physics of the Atmosphere

The change of pressure and density of the atmosphere with increasing altitude is based on physical principles. The calculation steps are adopted from Roedel & Wagner. The hydrostatic equation is,

$$\frac{dp}{dh} = -\rho g$$

where p is pressure, h is height, ρ is density and g is the acceleration of gravity (Roedel & Wagner, 2011, p. 65). For simplicity the ideal gas law is used.

$$p = \frac{\rho RT}{M}$$

In this equation R is the universal gas constant, T is the absolute temperature and M is the molecular weight of air. A thing to consider is that the temperature is not constant, but varies with height. The simple approach considers a linear decrease of temperature,

$$T = T_0 - L_0(h - H_0)$$

where L_0 is the standard temperature lapse rate. The density ρ can be explained with the ideal gas law and both sides of the hydrostatic equation need to be integrated.

$$\int_{P_0}^{P} \frac{dp}{p} = -\int_{H_0}^{H} \frac{Mg}{RT} dh$$

This leads to the barometric formula for a linear temperature gradient after the temperate is filled in.

$$P = P_0 \left(1 - \frac{L_0(H - H_0)}{T_0}\right)^{\frac{Mg}{RL_0}} \tag{4.1}$$

If in equation 4.1 reference height H_0 is set to sea level and the parameters for international standard atmosphere are used (temperature $T = 288,15$ K, air pressure at sea level $P_0 = 1013,25$ hPa, temperature lapse rate $L_0 = 0,65$ K per 100 m, exponent $Mg/RL_0 = 5,255$) this results in the international height formula that is valid for up to 11.000 meters, or the so called troposphere:

$$P = P_0 \left(\frac{1 - 0,0065 * H}{T_0}\right)^{5,255} = 1013,25 \left(\frac{1 - 0,0065 * H}{288,15}\right)^{5,255} \tag{4.2}$$

From equation 4.2 it is concluded that total air pressure P decreases with climbing altitude. Usually air pressure is indicated in mmHg and hPa (mbar), whereby 1 hPa equals 0,750 mmHg.

Dalton's law for partial pressure states that the total pressure of non-reacting gases is equal to the sum of the partial pressures of each individual gas (Silbergerg, 2009, p. 206). Therefore, the partial pressure of inspired oxygen (PiO_2) can always be calculated in relation to the total air pressure. The total pressure P equals $PiN_2 + PiO_2 + PiCO_2 + PiH_2O$, which also means the fraction (Fi) for each individual gas has to stay the same. At sea level the mean inspired oxygen pressure for dry air (ideal) is calculated from $PiO_2 = P \times FiO_2 = 760 \times 0,2095 = 159,22$ mmHg. And the mean inspired oxygen pressure for moist air (more realistic) is calculated from $PiO_2 = (P - PiH_2O) \times FiO_2$ with $PiH_2O = 47$ mmHg and this results in $PiO_2 = (760 - 47) \times 0,2095 = 149,37$ mmHg (Domej & Schwaberger, 2015b, p. 292). The calculated atmosphere, matching the standard atmosphere is listed in table 7 with steps of 1000 meters.

height H (m)	Air Pressure P (hPa)	Air Pressure P (mmHg)	Temp. T (°C)	dry PiO_2 (mmHg)	moist PiO_2 (mmHg)
0	1013,3	760,0	15	159,2	149,4
1000	898,8	674,1	8,5	141,2	131,4
2000	795,0	596,3	2,0	124,9	115,1
3000	701,1	525,9	-4,5	110,2	100,3
4000	616,5	462,4	-11,0	96,9	87,0
5000	540,3	405,2	-17,5	84,9	75,0
6000	471,9	353,9	-23,9	74,1	64,3
7000	410,7	308,0	-30,4	64,5	54,7
8000	356,1	267,1	-36,9	56,0	46,1
9000	307,5	230,6	-43,3	48,3	38,5

Table 7: Calculated atmosphere, matching the ICAO standard atmosphere 1968

4.2 Hypoxia Simulation

As mentioned before *hypoxia* means a lack of O_2, or rather insufficient O_2 supply of the body tissues. The term *hypoxemia* on the other hand describes the reduced O_2 saturation of hemoglobin in the blood. Hemoglobin is responsible for oxygen transport from respiratory organs to the rest of the body. A reduction of hemoglobin in the red blood cells causes hypoxia in the tissues. In altitude and sports medicine hypoxemia caused by *hypobaric* (terrestrial or artificial reduction of P) and *normobaric hypoxia* (artificial enrichment with N_2 to reduce O_2) are relevant (Ward et al., 2000, p. 47).

4.2.1 Hypobaric and Normobaric Hypoxia

For human respiration the partial pressure of inspired oxygen (PiO_2) in the air is important. This goes in conjunction with the percentage of O_2 in the air-gas-mixture humans are breathing. At sea level the PiO_2 is around 150 mmHg. A hypoxic environment has a lower PiO_2. As apparent in table 7 apparent, higher altitude results in reduced total air pressure (P) which also means a reduced PiO_2 because the percentage of O_2 (FiO_2 = 20,95%) does not change naturally. This is called *hypobaric hypoxia* and can be replicated in a decompression chamber. Another way to reduce the inspired oxygen pressure (PiO_2) is to reduce the O_2 fraction (FiO_2) by substitution with N_2 while the total air pressure P stays the same. This environment is called *normobaric hypoxia* (Härle, 2005, pp. 12-13).

Both forms of hypoxia result in a PiO_2 less then 150 mmHg. The equivalent FiO_2 for normobaric hypoxia to simulate altitude follows with

$$FiO_2 = 0,2095 \times \frac{P - PiH_2O}{P_{base} - PiH_2O} \tag{4.3}$$

where P is the pressure of the desired altitude to replicate and P_{base} is the base level pressure where the normobaric system is located. This equation includes the partial pressure of water (PiH_2O) with 47 mmHg, constant) because this is the more realistic approach (Domej & Schwaberger, 2015a, p. 295).

Equivalence of the models

For human physiology an exposure to hypobaric and normobaric hypoxia essentially has the same affect. Therefore the equivalence model can be calculated (Domej & Schwaberger, 2015a, p. 344).

The graph in figure 23 on the left shows the total air pressure, the partial inspired oxygen pressure (PiO_2) and the fraction of oxygen (FiO_2) for hypobaric altitude. This graph is based on the ICAO standard atmosphere from table 7. The graph on the right shows normobaric (simulated) hypoxia with a constant total air pressure and adjusted O_2 fraction to reach the according PiO_2 levels for altitude with a base in Graz at 383 m. In table 8 some detailed values (from eq. 4.3) are listed for normobaric hypoxia with a base in Graz at 383 meters.

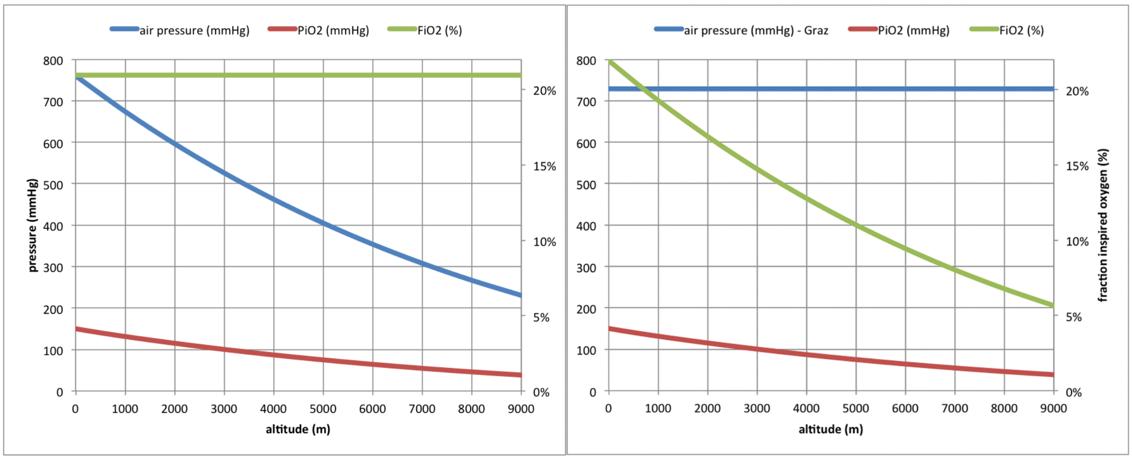


Figure 23: Comparison Between Hypobaric (left, "natural height") and Normobaric Hypoxia (right, base level of Graz at 383 m), own illustration

In the detail there are some differences between the hypobaric and the normobaric model that need to be discussed (Conkin & Wessel, 2008; Self et al., 2011). But as common in altitude medicine there is hardly any literature that is comparable due to different testing methods and no standardized parameters (Millet et al., 2012, p. 1783). There is indication that the equivalent FiO_2 is just true for ideal hypoxia and that the total air pressure P has an independent effect on hypoxia and Acute Mountain Sickness (AMS) (Loeppky et al., 2005, pp. 60 - 61). For conclusion, a hypoxia exposition for acclimatization purposes could be litte more effective in hypobaric hypoxia, because the body is exposed to the full stresses of altitude and not just the diminished O_2 content in normobaric hypoxia (Domej & Schwaberger, 2015a, p. 344).

Destination with altitude	Pressure P (mmHg)	dry PiO_2 (mmHg)	FiO_2 (%)
Graz, 383 m	726,1	152,1	20,95
Schöckl, 1445 m	638,5	133,8	18,25
Dachstein, 2995 m	526,2	110,2	14,78
Großglockner, 3761 m	477,0	99,9	13,26
Montblanc, 4810 m	415,6	87,1	11,37
Elbrus, 5642 m	371,7	77,9	10,02
Mount Everest, 8848 m	235,9	49,4	5,83

Table 8: Normobaric hypoxia with corresponding FiO_2 based in Graz, 383 meters, adapted from Domej & Schwaberger (Domej & Schwaberger, 2015a, p. 296)

N_2 Exposure

Molecular Nitrogen is a colorless, odorless and tasteless inert gas. In simulated altitude environments partial pressure of inspired nitrogen (PiN_2) up to 692 mmHg can be generated (Pedlar et al., 2005, p. 356). This is equivalent to a height of 7000 meters at sea level (FiO_2 0,08; FiN_2 0,91) and 15 % above the normal level of PiN_2. Inhalation of 100 % nitrogen would be fatal due to a lack of CO_2 and O_2 which is needed for respiration. Nitrogen therefore is just dangerous if it suppresses oxygen below a life sustaining minimum. Any consequential damages of gas mixtures with higher then natural FiN_2 are not documented (Domej & Schwaberger, 2015a, p. 345).

4.2.2 Technical requirements

In altitude and hypoxia research simulated altitudes are of increasing importance, whereas the implementation of a normobaric hypoxia system seems to be the easiest way. Hypobaric chamber systems to simulate hypoxia have higher acquisition and operation costs, because they need a very robust chamber and controllable vacuum technology (Domej & Schwaberger, 2015a, p. 346).

There are different ways to generate nitrogen for normobaric hypoxia simulation facilities. Most of the time **pressure swing absorption (PSA)** is used because it is energy saving in comparison to temperature swing adsorption. PSA technology is based on the pressure changes that are applied to special adsorptive materials, called zeolites. These zeolites are natural or synthetic with the capacity to bind particles to its surface. With PSA a N_2 purity of 99,9 % can be reached (Domej & Schwaberger, 2015a, p. 348).

More frequent nowadays, **membrane gas separation** is used to supply hypoxia simulations with oxygen reduced air mixtures. Steam, oxygen, nitrogen, noble gases and carbon dioxide have a different molecular structure. Therefore they diffuse at different rates through the membranes. Oxygen has a higher degree of diffusion and it is easily extracted from air. Nitrogen has a low degree of diffusion and it takes longer to permeate through the membrane as displayed in figure 24. The purity of the desired gas depends on the flow velocity. With a variation in pressure and volume flow rate the amount and purity of nitrogen is controlled. For N_2, purity up to 99,5 % is possible with membrane gas separation and this is sufficient for the simulation of hypoxia (Domej & Schwaberger, 2015a, p. 349).

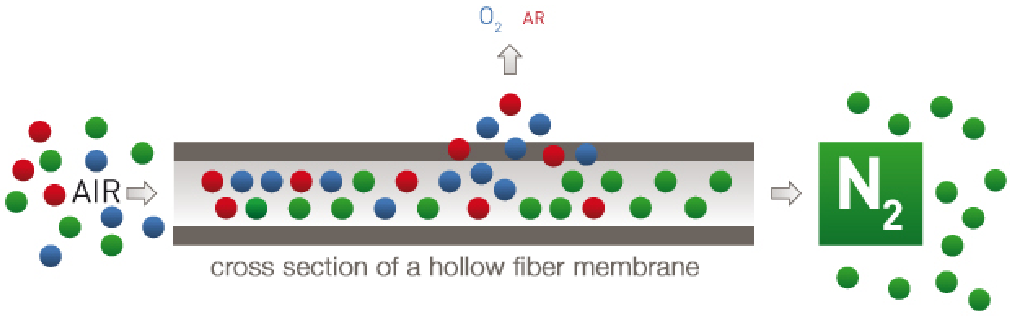


Figure 24: Membrane Gas Separation (INMATEC, 2016)

Operating a Normobaric Hypoxia (NH) Chamber

Besides the nitrogen system another important component is missing to run a NH simulation. Inside of the chamber or room there has to be a oxygen sensor that can be controlled by a gas measurement device from time to time. The control of O_2 as well as CO_2 should be redundant to ensure highest accuracy. Modern oxygen measurement devices have to consider humidity as well as the PiO_2 shifts with changing PiH_2O because of Dalton's law. Oxygen sensors with zirconium oxide have the most accuracy and longevity. (Domej & Schwaberger, 2015a, p. 350).

If training at moderate to high intensity takes place in the chamber a climate system to keep humidity and temperature at appropriate levels is necessary. To control the different parameters like the nitrogen enriched air flow, the O_2 levels for equivalent altitude, the humidity and potentially the temperature, electric control and software are needed. With manual control it is not possible to provide the same accuracy. Another consideration is the filtration of hypoxic gas mixture (for example HEPA filter) before it feeds the atmosphere in the chamber (Domej & Schwaberger, 2015a, p. 351).

The costs of an NH system mainly include the nitrogen generation, the oxygen sensor, potentially a climate system and a room or container, whereas a NH chamber has paid off fast in relation to traditional altitude training. Moreover the training in a chamber is not time, weather or location dependent. Furthermore, is the necessary training height and required training facility also not always available in the country or region. Intermittent Hypoxia (IH) protocols with shorter intervals in hypoxia are also not possible with traditional altitude training. Each person that is going to be exposed to altitude simulations for training or research purposes should be able to tolerate the 3000 m NH equivalent in relaxation for at least 30 minutes without symptoms. Before exposure to altitude, blood pressure, heart rate and pulse oximetry measurements should be recorded to determine the resting values to better interpret and prepare for measurements under exhaustion

(Domej & Schwaberger, 2015a, p. 352).

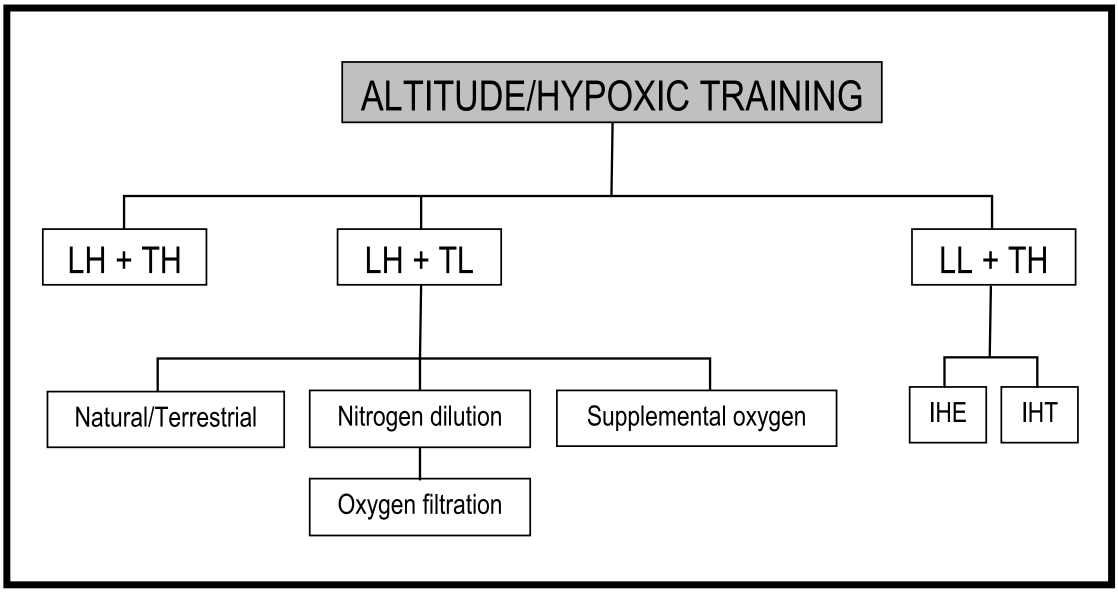
4.2.3 Preacclimatization

Normally, altitudes up to around 2700 meters with NH equivalent FiO_2 higher than 0,15 are tolerated by people without previous related diseases. Acclimatization describes the process of adjustment by the organism to the exposed altitude. In NH environment, same as on natural altitude, the acclimatization is very time dependent and individual. Even several hours of exposure to hypoxia do not guarantee better O_2 transport capacity in the test person. The longer the exposure to the desired altitude lasts, the better and more complete the acclimatization will be (Burtscher, 2010, pp. 364).

Respectively to endurance performance in middle heights, as less as seven intermittent hypoxia sessions for one hour at rest (4500 m / 12,5% O_2 equivalent) will not bring a significant advantage (Faulhaber et al., 2010, p. 513). Only longer acclimatization time, for example, 5 times per week, 4 hours per day for 3 weeks, at an equivalent altitude of 4300 m is able to reduce the severity of AMS significantly (Muza et al., 2006, p. 338). Strategies for acclimatization that are based on natural altitude are more effective then those based on NH facilities (Fulco et al., 2013, p. 55).

4.3 Training in Hypoxia

High-altitude training is mainly used by professional athletes in order to increase their power output at the lower altitude level where they usually perform. Despite the fact that there are still controversies about the efficacy of altitude training, athletes are using it in preparation for competitions at elite levels. Originally height training implied working and living: **live high - train high**, at moderate altitude around 2000 m to increase the maximal oxygen uptake (VO_{2max}) at sea level. Alternative concepts like **live high - train low** and **live low - train high** are variations of Intermittent Hypoxia (IH) protocols. In *live high - train low* protocols the athletes spend most of their day in hypoxia (natural or simulated) and intensive training sessions are done at normoxic conditions, because is not possible to stay at hypoxia the whole time and train at the same intensity as on sea level. On the other hand, the concept of *live low - train high* is trying to increase the intensity with training in a hypoxic environment, with the rest of the day, as well as recovery, taking place in normoxia (Faulhaber & Wille, 2015, p. 357). Figure 25 illustrates the different models currently used by elite athletes.



IHE (intermittent hypoxic exposure), IHT (intermittent hypoxic training), LH + TH (live high + train high), LH + TL (live high + train low), LL + TH (live low + train high)

Figure 25: Models of Altitude Training(Wilber, 2011, p. 272)

4.3.1 Intermittent Hypoxia

Intermittent Hypoxia (IH) is defined as the repeated exposure to reduced oxygen content that is interrupted by phases with a normal oxygen content (Neubauer, 2001, p. 1594). In general IH protocols are categorized by three parameters.

The **intensity** of the hypoxia is regulated with the PiO_2. The **duration** of the hypoxic phases can vary from a few minutes up to some hours. Shorter hypoxic phases normally are repeated whereas longer phases occur just once a day. In general there is also distinguished between phases of hypoxia with or without **physical activity**. If work is done in hypoxia, the intensity of the activity is important (Burtscher, 2005, p. 65).

The most popular approach to increase the aerobic capacity of athletes incorporates increasing hemoglobin in order to increase the oxygen transport capacity of blood. With older people, IH protocols with short hypoxia cycles from 3 to 5 minutes have shown an increase in work capacity connected with increasing hemoglobin mass (Burtscher et al., 2004, p. 247). With athletes these passive protocols seem not to be intense enough to increase the aerobic capacity. IH with more than 12 hours passive hypoxia at a minimum of 2000 meters seems to be the right stimulus to increase performance. After 4 weeks, the hemoglobin mass of athletes was 3 to 10 % higher (Robach &

Lundby, 2012, p. 305). This is connected with a higher oxygen uptake (VO_{2max}) (Carr et al., 2015, p. 776).

In light of these considerations, the concept of *live high - train low* is understandable. This model is also called Intermittent Hypoxic Exposure (IHE) because it is simply the exposure to hypoxia without training. In some studies, a performance increase of 1 to 2 percent in professional athletes is confirmed (Levine & Stray-Gundersen, 1992; Wehrlin et al., 2006; Wilber et al., 2007). But there are also some more recent and controlled studies that question the results which can be achieved with *live high - train low* (Siebenmann et al., 2012). A reason for different results could be explained with standard hemoglobin levels being very different in individuals. This could mean that athletes with lower base levels of hemoglobin will benefit more from *live high - train low* than those with higher levels of hemoglobin (Faulhaber & Wille, 2015, p. 358).

In order to increase the maximal oxygen uptake with nearly no active training and just the intensity of hypoxia, a lot of time ir required. Not every athlete is willing to sleep or spend that amount of time in a closed environment where altitude is simulated. A more intense method to use hypoxia for training is IH with a training stimulus at altitude, *live low - train high*. This method is used by athletes with intense efforts of training in hypoxia and therefore is called Intermittent Hypoxic Training (IHT) as mentioned in figure 25. Another possibility is to train intensively in normoxia and use hypoxia for the rest periods. It is then called IHE again, but with shorter hypoxic expositions. A summary from Wilber reveals that the efficacy of *live low - train high* is not overly persuasive. Especially with elite level athletes there is additional research needed in order to find out how to achieve results with these IH protocols (Faulhaber & Wille, 2015, p. 359).

IHT seems more beneficial than IHE to enhance the performance of athletes. At the molecular level in skeletal muscle tissues, the intensity of exercises at hypoxia also play a role. Muscle adaptions for aerobic and anerobic exercises are stimulated the most with very intensive training at high altitude. It is not clear if IHT could increase VO_{2max} because of the short exposition to hypoxia, but the athletic performance is likely to improve. This happens with high intensity exercise (above lactate threshold) which results in an increase of respiratory efficiency and higher lactate threshold level. Millet et al. propose more sophisticated altitude training methods where *live high - train low* is combined with *train high*. This new approach includes five nights sleeping at 3000 m and two at sea level with mainly training at sea level except for a few very intense threshold trainings for two to three times per week. Another study suggests respiratory muscle training (RMT) in hypoxia in order to increases ventilation which results in better VO_{2max} (Esposito & Ferretti, 2010, p. 219).

4.3.2 Acute Mountain Sickness

Above altitudes of 2500 meters, the human organism has to acclimatize to oxygen conditions. If this is not possible, different forms of diseases related to altitude can occur, and Acute Mountain Sickness (AMS) is the most frequent. The faster people climb higher without a period of preacclimatization, the higher the possibility to contract AMS. Furthermore, the severity increases with higher altitude (Schneider et al., 2002; Bärtsch & Swenson, 2013). It has been shown that short exposures to hypoxia as preacclimatization can reduce the risk of AMS. IH protocols with repeated expositions of a few hours have shown initial acclimatization results, which offers a cost and time saving alternative to longer acclimatization time when climbing a mountain (Faulhaber & Wille, 2015, p. 359).

In summary, the influencing factors for AMS are: absolute height and rate of ascending, precious acclimatization, individual sensitivity, age and other diseases (Härle, 2005, p. 17). The symptoms include: headache (= main symptom), lack of appetite, nausea, tiredness, dizziness and insomnia. They start gradually and usually peak on day two or three at altitude. If some of these symptoms occur and are not improving, that individual should descend for a few hundred meters and try to acclimatize on this lower level first before ascending back up (Ward et al., 2000, p. 215).

A minimum of 1 to 3 hours of IH at 4000 meters or above could be enough for successful acclimatization. But there is no indication that such a short hypoxia exposition works for everyone. The longer the exposure, the better and more complete the acclimatization will be. A practical approach suggests sleeping at above 2000 meters, or recurring expositions of 3 to 4 hours at above 4000 meters. A very long altitude exposure may be impractical if done in simulation and therefore natural altitude should be preferred. The optimum or minimum dose of IH to prevent AMS remains unanswered. Further research may bring information to unresolved issues (Faulhaber & Wille, 2015, p. 360).

4.3.3 Increase Oxygen Transport

A pigment withing red blood cells called hemoglobin is responsible for oxygen transport in humans. The maximum oxygen uptake (VO_{2max}) would be higher with more hemoglobin. Erythropoietin (EPO) can stimulate the production of red blood cells and this will also increase hemoglobin levels (Gaudard et al., 2003, p. 188). There are four main ways to increase oxygen delivery related to hemoglobin count. Simulated hypoxia, terrestrial altitude, blood doping and EPO have been shown to increase hemoglobin mass in red blood cells. Two of them are illegal and two of them are not like the exemplary figure 26 from the movie *Bigger, Stronger, Faster** shows (Bell et al., 2008).

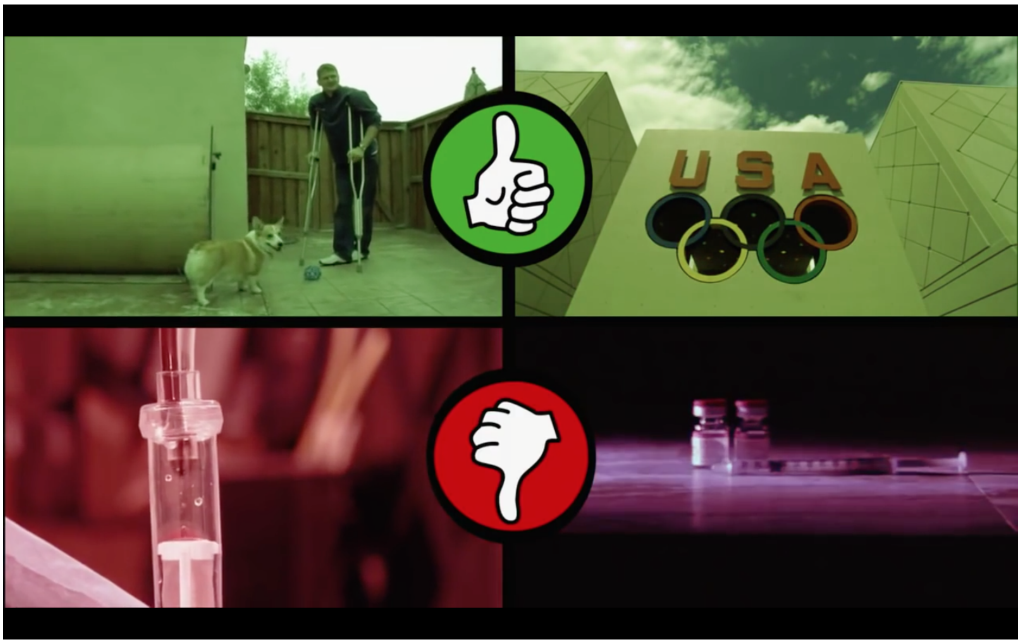


Figure 26: 4 Ways to Increase Oxygen Transport: 1. Simulated Hypoxia, 2. Terrestrial Altitude, 3. Blood Doping and 4. EPO (Bell et al., 2008, TC 00:33:33)

Simulated hypoxia As in the whole of section 4.3, endurance athletes mainly use different approaches for altitude training in simulated hypoxia: hypoxic apartments (live high - train low), hypoxic sleeping devices and IH protocols (live low - train high). The potential benefit of hypoxic rooms is not easy to quantify. A study from Berglund et al. shows a significant increase in hemoglobin and serum EPO concentrations. In healthy males that were continuously exposed to normobaric hypoxia for 10 days, serum EPO levels initially increased about 350 % but then after 10 days, leveled off to just about 75 % above normal level. Furthermore, the study resulted in a significant increase in hemoglobin and a decrease in iron concentration (Berglund et al., 2002, p. 226). By official sports authorities the use of normobaric hypoxia for training is not considered a doping method (Gaudard et al., 2003, p. 193).

Altitude Training It is well known that hemoglobin mass and red cell volume increases because terrestrial hypoxia stimulates erythropoiesis. But it is still hard to quantify the benefits of this legal way to increase EPO and hemoglobin levels (Gaudard et al., 2003, p. 192).

Blood Transfusion In the 1970s and 1980s a lot of blood transfusions were used by athletes. Since it is clear that blood doping increases hemoglobin that leads to higher VO_{2max} it was banned by the International Olympic Committee (IOC).

EPO This hormone is mainly generated by the kidneys. DNA techniques have allowed to develop a recombinant form of EPO. It has been used as a anti-anaemic drug in the US since 1985. It was most likely used by elite level athletes at the same time to increase their performance. Their physical work capacity increased and their aerobic threshold shifted to higher workloads because of the better oxygen supply to muscles. Despite the performance enhancing benefit, long term usage comes with risks such as hyperviscosity, thrombosis and hypertension. It has been banned by the IOC since 1990 (Gaudard et al., 2003, p. 190).

VO_{2max} is the main limiting factor in endurance sports, and there exist several methods to increase it. There are many different drugs that achieve the same results and increase the amount of EPO in the human body. Each one of these drugs is banned by the IOC and can cause serious health risks. Hypoxic training seems to be a natural way to increase the oxygen transport ability of blood (Gaudard et al., 2003). In the next chapter the insights about high-altitude training in addition to previously mentioned theories about innovation and modularization will help with NHT configuration development.

5 Configuration Development

In this chapter the previous mentioned theoretical parts about *Innovation*, *Product Development* and *High Altitude Training* are brought together in order to develop a product configuration tool for the Normobaric High Altitude Training (NHT) system.

At first Modular Function Deployment (MFD) is used to determine the modules. A business model canvas is also created and used to support MFD and to evaluate the customers needs which is very important in the innovation process.

After the concept, the configuration tool is built in Microsoft Excel because it sets the foundation for future database implementation. The tool is adapted to existing standards within AMST. In the end the configuration file is demonstrated and different variants of the NHT sytem are calculated and compared.

5.1 Modularization Concept

First of all, the concept for NHT in regard to modularization is developed. Therefore, MFD from Erixon, as mentioned earlier is used. The first step is to be clear about the customer requirements and to clarify the product specifications with the help of a business model canvas and QFD. Afterwards the technical solutions are outlined and the concept for modularization is generated using the MIM. The chosen concept finally needs evaluation and further development. In section 3.2.3 the process is found in more detail.

5.1.1 Customers Needs

The first step in the MFD is to figure out what the customer wants and for what needs they are ready to pay. Therefore a business model has been generated and this business model was translated into a QFD. At the end, the customer needs are clear and can be specified.

Business Model Generation

In January 2016 a workshop for business model generation was held at AMST Systemtechnik. The participants were Richard Schlüsselberger jr., Rainer Schlüsselberger, Rudolf Gann, Norman Eisenköck, Michael Mayerhofer, Robert Cresnik and Andreas Schranzinger. The aim of this two hour course was to explain the methodology from Osterwalder & Pigneur about business model generation and use it to generate a new business model for NHT. A photograph is seen in figure 27). As suggested, post-its have been used, because it is easier to move the elements. The nine blocks have been filled out in a random order without going into further detail, as suggested by Osterwalder & Pigneur.

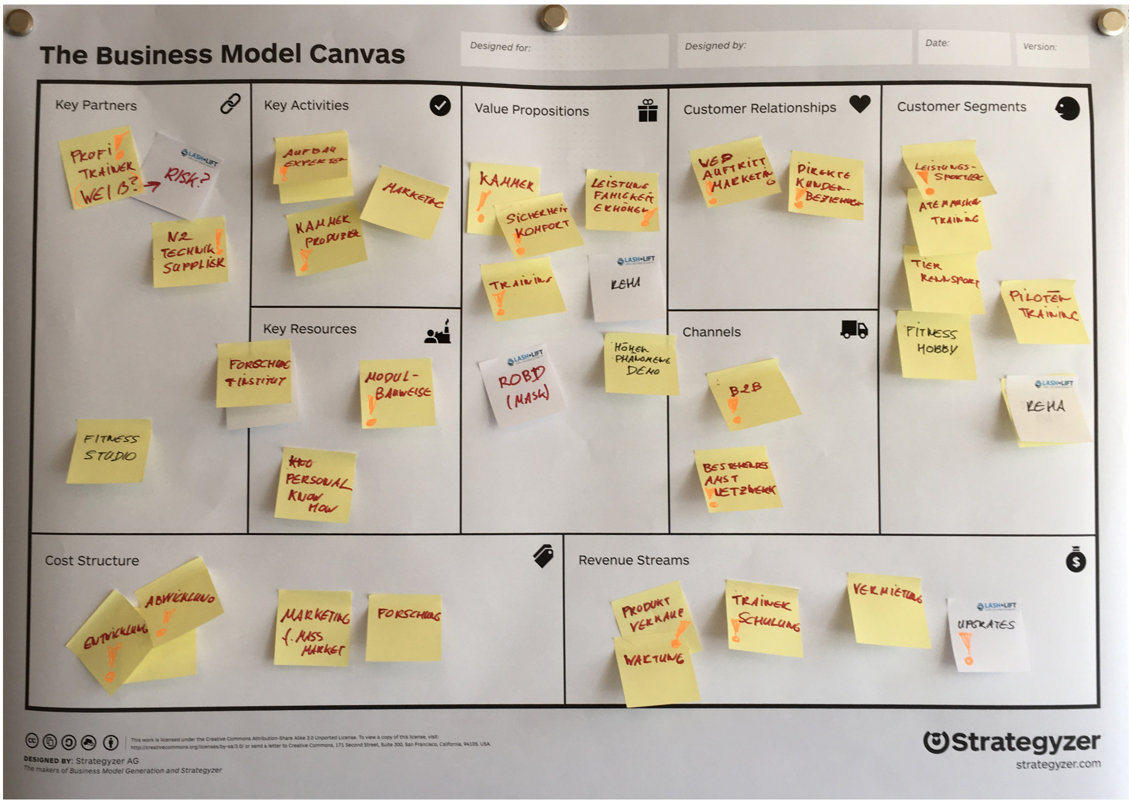


Figure 27: Photo Business Model Generation, at AMST in January 2016

During the development process, some minor changes have been made and the current model is shown in figure 28.

The main user segment for the Normobaric High Altitude Training is elite level athletes. In order to serve them, the *main customers* are sports federations like the ÖSV (Austrian Ski Federation), wealthy sports clubs, sophisticated training centers and even top level coaches who are trying to bring the training of their athletes to the next level. To serve these ambitious customers a simple altitude mask is surely not enough.

The *value* that AMST offers includes a professional normobaric hypoxia simulation in order to increase the athletes performance. This multi purpose system can be used for training, recovery and acclimatization. Additional value is generated with training control in order support planning and monitoring demands of professional training. This all comes with high safety and comfort standards.

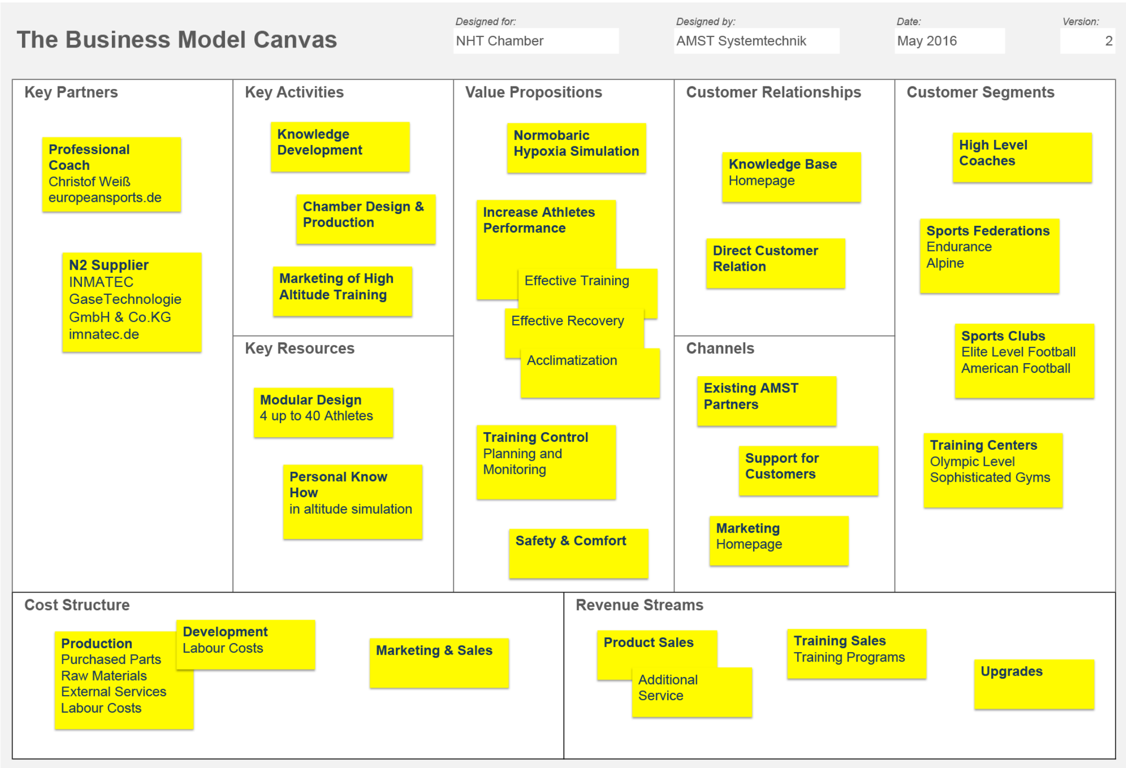


Figure 28: Current Business Model for NHT, own illustration

AMST is enforcing *direct customer relation* and offers some basic level knowledge about altitude training and the usage of the system. Because it is dangerous to operate the chamber without knowledge about how the human physiology is going to react when work is taking place in hypoxia, extensive instruction is necessary.

To first get in contact with the customers, AMST can rely on its existing *channels* but will additionally offer information around the new product on the Internet. Furthermore, marketing will be done in the future to access new market segments.

To create value, the firm can rely on existing *resources* in the field of altitude simulation. Discussions about modular design will help to serve the customers' specific needs and optimize the selling process.

The *key activities* involve design and production of a robust chamber system and development of knowledge with modular design. In addition, hypoxic training needs to be promoted.

As mentioned earlier, it is important to know how athletes react when training in hypoxia and the knowledge comes from top level coach, Christof Weiß, who is a *partner* in the development procedure. Further research as to how NH affects athletes can also be done with the NHT chamber from AMST.

The *cost structure* includes the development of a modular system, which mainly involves labor costs, and the production costs that involve the purchased parts, raw materials, external services and wages of the workers. In order to increase sales, a marketing budged is also needed.

Revenue is generated through product sales and can be extended with additional services like software for specific training equipment. Furthermore, upgrades will also generate income.

The result of this workshop for business model generation probably did not reveal the final business model, but it resulted in a common knowledge about the new product that is going to be developed and it serves as a guideline to roughly sketch each part roughly.

Quality Function Deployment

The business model canvas is also serving as a creativity tool and forces one to think holistic about the NHT chamber. The first step of MFD, to determine "what" the customer wants, is influenced by the business model which helps the latter steps.

The customers' requirements secondly are then assigned with importance factors for further calculation. The most important **customer requirements** tend to be the *high altitude simulation* and the *price to performance ratio*. Furthermore, the system needs to be *robust* and *easy to use* as seen in figure 29. The first **functional requirement** is the *modularity* of the system, as usual when following MFD.

# Row	Relative Importance	Importance	Customer Requirements "Whats" / Functional Requirements "Hows"	Modular Sytem
1	15,2	5	High Altitude Simulation	
2	9,09	3	Effective Training	
3	9,09	3	Climate Control	
4	12,1	4	Easy to Use Sytem	
5	9,09	3	Multi Purpose System	
6	12,1	4	Robust System	
7	15,2	5	Price to Performance Ratio	
8	3,03	1	Personal Service Partner	
9	6,06	2	Training Room Comfort	
10	9,09	3	Monitoring/Planning of Training	

Figure 29: Customer Requirements in QFD, own illustration

In the next step, some **competitive products** are compared to the concept of AMST. As most of the literature suggests, Hypoxico offers the most advanced altitude training systems. Their altitude rooms are very similar to the chamber concept and the altitude training mask covers another possibility to simulate hypoxia. Furthermore, the elevation training mask, that is essentially a respiratory breathing device at the very low cost side, is compared in figure 30. Mask systems have a big advantage in price, but that price always comes with cutbacks in comfort of training and efficiency. The chamber or room systems from Hypoxico cannot be critiqued as the product was not analyzed in detail and just listed for comparison.

The next step in QFD is to determine the **functional requirements** in order to fulfill the customer requirements. Most of the time these "hows" are quantitative criteria that have a target value assigned. For example, the *maximum altitude level* for training is 4500 meters to cover different IH training protocols. Another criteria is the *set up time* for the chamber to reach designated altitude. This value should be minimized and not exceed half an hour. In figure 31 all the functional requirements with additional direction of improvement and target values are displayed for further study.

# Row	Relative Importance	Importance	Customer Requirements "Whats" \ Functional Requirements "Hows"	AMST NHT	Hypoxico Altitude Rooms	Hypoxico Altitude Training Mask	Elevation Training Mask 2.0
1	15,2	5	High Altitude Simulation	4	4	4	1
2	9,09	3	Effective Training	5	4	3	3
3	9,09	3	Climate Control	5	3	0	0
4	12,1	4	Easy to Use Sytem	3	4	3	5
5	9,09	3	Multi Purpose System	4	4	3	1
6	12,1	4	Robust System	4	3	2	4
7	15,2	5	Price to Performance Ratio	3	2	5	3
8	3,03	1	Personal Service Partner	4	3	2	0
9	6,06	2	Training Room Comfort	4	3	2	3
10	9,09	3	Monitoring/Planning of Training	4	3	2	2

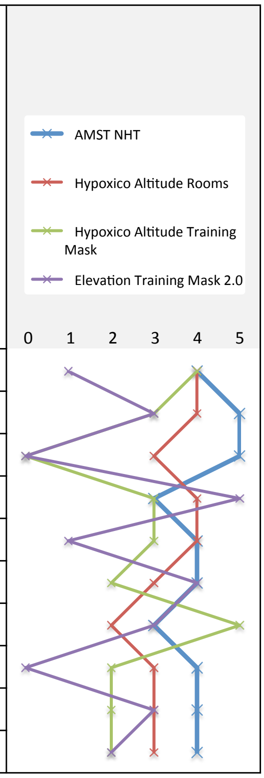


Figure 30: Competitor Analysis in QFD, own illustration

At the top of figure 31 there is the correlation between the different functional requirements. It is visible that the altitude level correlates positive with the performance of the nitrogen system. Whereas a higher altitude level has a negative correlation with the set up time of the system. Additionally there is a difficulty rating for each target value to achieve.

After the correlations, the **relationship matrix** in the middle is filled out. The customer requirements and functions can have a strong (9), moderate (3), weak (1) or no (0) relationship. With this matrix, it is possible to calculate the importance of each functional requirement and derivate the main specifications for further development. The *nitrogen system*, the *modularity* and the *adjustable altitude level* are the most important functions of the NHT.

5.1.2 Technical Solutions

This is the second step of MFD and after the QFD there is a good overview about the requirements of the NHT system. Nitrogen is needed to generate normobaric hypoxia. In section 4.2.2, two

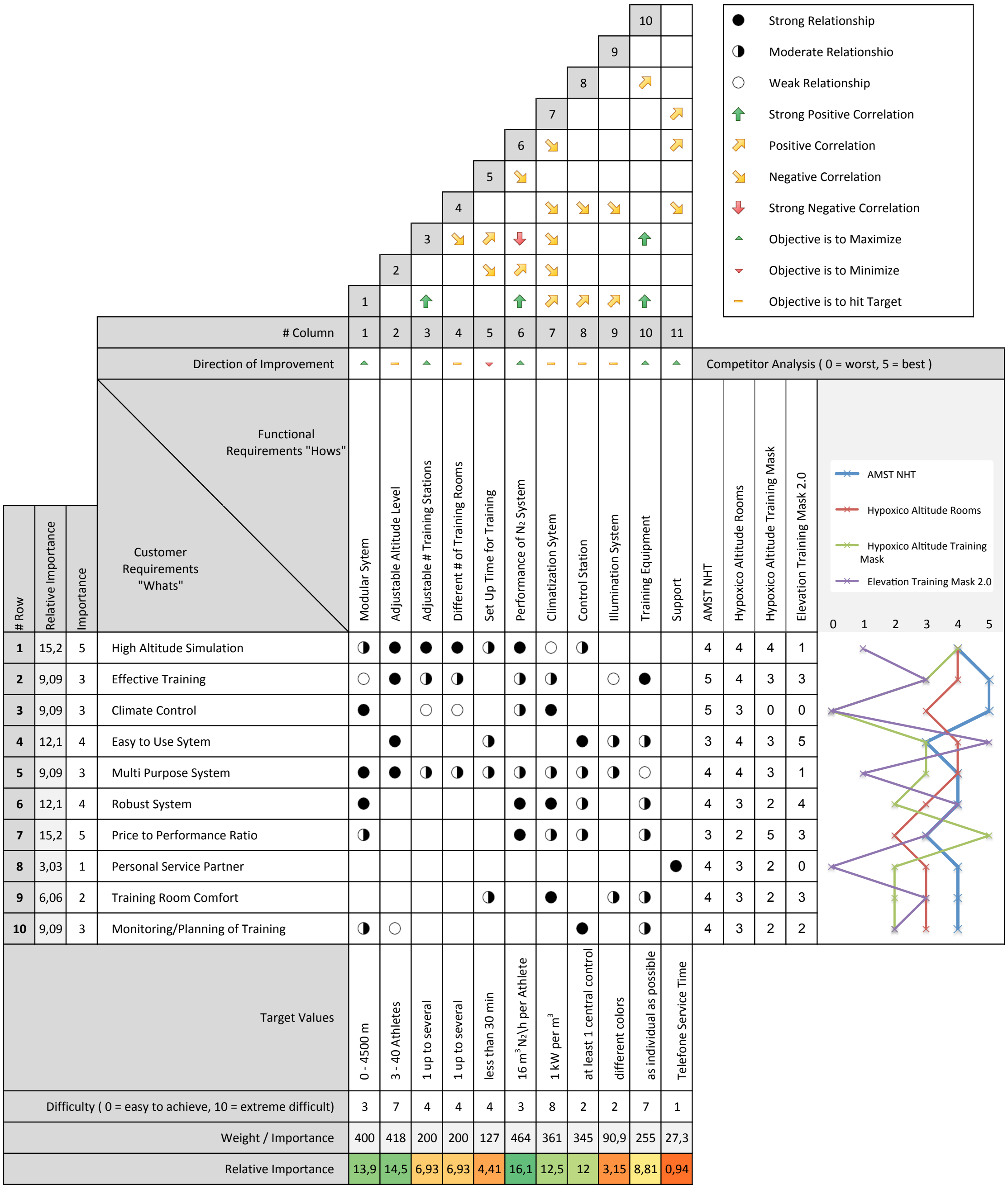


Figure 31: Quality Function Deployment, own illustration

possibilities to generate N_2 are mentioned: the PSA with a purity of 99,9 % and the membrane gas separation with a purity of 99,5 %. In the case of hypoxic simulation, the membrane gas separation is sufficient and also the cheaper option. The target value is 16 cubic meters of nitrogen per athlete per hour for the nitrogen supply and the altitude level of the chamber needs regulation from the base level up to 4500 meters.

Description	N2 Capacity (Nm^3/h)					
Nitrogen content (%)	99,5	99,0	98,0	97,0	96,0	95,0
IMT MN 1050	4,70	6,70	11,00	15,00	20,00	25,00
IMT MN 1150	7,00	11,00	19,00	26,00	33,00	40,00
IMT MN 1250	14,00	22,00	38,00	52,00	66,00	80,00
IMT MN 1350	21,00	33,00	57,00	78,00	99,00	120,00
IMT MN 1450	28,00	44,00	76,00	104,00	132,00	160,00
IMT LNX 1150	-	54,00	89,00	121,00	161,00	201,00
IMT LNX 1250	-	108,00	178,00	242,00	322,00	402,00
IMT LNX 1350	-	162,00	267,00	363,00	483,00	603,00
IMT LNX 1450	-	216,00	356,00	484,00	644,00	804,00
IMT LNX 1550	-	270,00	445,00	605,00	805,00	1.005,00
IMT LNX 1650	-	324,00	534,00	726,00	966,00	1.206,00
IMT LNX 1750	-	378,00	623,00	847,00	1.127,00	1.407,00
IMT LNX 1850	-	432,00	712,00	968,00	1.288,00	1.608,00
IMT LNX 1950	-	486,00	801,00	1.089,00	1.449,00	1.809,00
IMT LNX 2050	-	540,00	890,00	1.210,00	1.610,00	2.010,00

Table 9: Membrane systems with different purity INMATEC (2016)

Gas Membrane Separation

There exist different suppliers for membrane gas separation systems. Imnatec GaseTechnologie GmbH has the advantage of just being 200 kilometers away from the AMST headquarter which promotes close cooperation. Imnatec offers different sizes and therefore different volume flow and purities of nitrogen membrane systems. In table 9 the capacity from two systems, MN and LNX, are listed. This data is also used in the configuration file, but only the maximum nitrogen capacity is considered, because a purity of 95 % is sufficient for the purpose of altitude simulation.

The amount of nitrogen required mainly depends on the number of athletes training at the same time. Due to losses, the minimum amount of nitrogen is calculated in order to choose a system from table 9.

Room Concept

The main idea is to have one room for training or rehabilitation that is regulated to a certain altitude. If air conditioning is to be installed, the room should be kept as small as comfortable for the desired number of athletes. Regarding the nitrogen system, the room size does not really matter, as only the number of athletes and the amount of losses due to leakage are important. A bigger room requires a higher heating and cooling output for the air conditioning system which causes unnecessary expenses if the space is not needed. There are three different types of possible training rooms.

Mobile A mobile room is a training room in a special container based on a truck. This room is limited to four athletes with one coach because the legal requirements do not allow bigger structures on the backside of a truck.

Container This is the most flexible solution with containers from BOX&BOX. They offer a wide range of prefabricated containers and are adaptable to customers specific requirements. The smallest single container has the dimensions of 2.43 x 2.43 x 2.70 (Length x Width x Height in meters). The biggest solution is a modular concept of three connected containers with 12.00 x 7.26 x 2.70 meters. A customer of an NHT container system can choose from various dimensions as long as the container offers enough space for the athletes.

Building Existing infrastructure is used and converted into normobaric training facilities. There are no limits to the room sizes, but of course someone must always consider the cost-benefit ratio.

If separate sleeping or rehabilitation facilities are required, then this is possible with an additional container or another room in a building. The mobile system cannot be used for training and rehabilitation simultaneously.

Training Equipment

To ensure modularity and a high degree of individualization the customer is able to choose between different training equipments supported by AMST.

Bike Ergometer from SRM A high performance bike ergometer that can simulate biking loads and evaluate the training with very high precision. This product is mainly used in sports science because of its accuracy and reproducibility of test results.

Concept2 row ergometer An indoor rowing machine that has the benefit of working the whole body, without a great amount of joint stress. This rower can be used for high intensive interval training because it has a very low rate of injury, even under fatigue.

Trueform Runner This is a natural running treadmill that forces better running mechanics and therefore improves leg stroke and technique. Furthermore, it is also suited for high intensity intervals because the treadmill accelerates as the athlete runs faster.

Spectra Elite large surface treadmill A treadmill with a bigger surface that can be used for skating, as well as for two runners at the same time. The elevation as well as the speed can be adjusted on this powered treadmill.

Ercolina Arm Stroke This is special piece of equipment for training the upper body in order to improve in cross-country skiing.

This training equipment is recommended and can be supported by AMST software for training. Individual equipment can of course be used, but if software support is desired, then this needs further investigation.

5.1.3 Generate Concept

In this third step of MFD, the module candidates for the NHT are determined. With the use of Module Indication Matrix (MIM), the function carriers are assessed with each module driver and the result is shown in figure 32.

A large *carry over* means that parts can be used for more than one product generation. This is the case with the nitrogen and air conditioning system, as well as the developed software. In the upcoming years there will probably be no great *technology push* and there will also be no great change in *production planning*.

The nitrogen, air-conditioning and training room structure have variance in their *technical specifications* but there is no big influence of the product *styling* at all. Regarding training equipment, the *common units* can be used more then once. The same is true for illumination elements and performance monitors. *Process organization* and *quality testing* has no big influence on the modules. The purchased parts, like the nitrogen system, measurement devices and training equipment have a big impact on *blackbox engineering*.

A damaged measurement device is also easy to change and therefore *maintenance and service* friendly. Major *upgrades* of the NHT system are provided on the hardware and software side. As most of the modules are purchased, the *recycling* possibility is unclear.

Module Driver \ Function Carrier		Nitrogen Membrane System	Compressed Air System	Air-Conditioning	Air-Gas Mixture System	Ventilation Training room	CO2 Measurement Device	Oxygenmeasurement	Humidity and Temp. Meas.	Training Room Structure	Computer & Network System	Performance Monitors	Altitude Control Unit	Illumination	Power Distribution	Software	Spectra Elite	SRM Ergometer	Ercolina Upper Body	Concept 2 Ergometer	Safety System for Threadmill
Development and Design	Carry-over	●	●	●	●	◑	●	●	◑	○	○		○	◑		●					
	Technology push										◑	◑	◑			◑	◑	◑	◑	◑	
	Production planning															◑	◑	◑	◑	◑	○
Variance	Technical specification	●	●	●	●					●		◑		◑	◑		○	○	○	○	
	Styling									◑				◑							
Production	Common unit								◑	○		●		◑			◑	◑	◑	◑	
	Process/Organization	◑	◑	◑	◑					◑						◑					
Quality	Seperate testing	◑	◑	◑	◑					◑							◑	◑	◑	◑	
Purchasing	Black-Box engineering	●	●	●	●	◑	●	●	●	◑	○	◑	○	●	○		●	●	●	●	○
After sales	Service and maintenance	○	○	○	○	●	●	●	◑					◑		◑	○	○	○	○	
	Upgrading										●	◑		◑		●					
	Recycling									●							◑	◑	◑	◑	
● 9 ◑ 3	Weight of Driver vertically summarised	34	34	34	34	15	27	27	18	32	14	21	5	27	4	30	26	26	26	26	2
○ 1	Module candidates	✓	✓	✓	✓		✓	✓		✓				✓		✓	✓	✓	✓	✓	

Figure 32: Module Indication Matrix (MIM), own illustration

Defined Modules

From the MIM, the modules are determined. The nitrogen system, the air conditioning system and the training room are the main module drivers, regardless of the chamber type.

Nitrogen System As the main component of the NHT system, it provides the main functionality of altitude simulation. This module includes the system for nitrogen generation and the necessary compressed air system. The amount of air needed is dependent on the amount of nitrogen, which relates to the number of athletes training.

Air-Conditioning The air-conditioning modules includes the air-handling unit outside of the training room and the air-gas-mixture system inside the room.

O2-CO2-Measurement The measurement devices for oxygen and carbon dioxide are combined into one module.

Training Room This module describes the space for training or rehabilitation. It can be a container, a existing room in a training facility or mobile system with its structure included.

Illumination A small, but still important module is the illumination system that is responsible for comfort and emotions during training which can lead to increased training performance.

Software The software as a module is independent from everything else and is developed separately.

Training Equipment In this module the different training equipments are pooled into one category.

Further steps in MFD include the evaluation of the concepts and improvements of the modules. These steps are not included in this thesis because the evaluation and improvement will happen when the first products are sold and feedback about the system is gained. With the existing knowledge the specifications and input parameters can be determined and it is possible to implement a configuration file with Microsoft Excel which is implemented in the next section.

5.2 Building the Configurator

In this section, the configurator with its capabilities and limitations is explained. The configuration file can calculate the price of different NHT variants and therefore needs some input parameters. Firstly, it was important to determine the input parameters in order to serve the different customers' needs. To develop a configuration based on the same inputs for every customer a basic understanding of the technical correlations was necessary. Due to the importance of the input parameters they are explained in detail.

Dependent on the inputs, further calculations are performed with the stored data in the background. The database is built in Microsoft Excel and optimized in a way that it can be upgraded and future knowledge about the NHT system can be implemented.

5.2.1 Specifications

The raw specifications can be derived from the business model and the QFD. The modular design of the product takes the highest priority to guarantee better order processing and the usage of scaling effects. To restrict the product variety, some limiting parameters are defined in table 10. The training chamber can be built as a mobile container on a truck, as a standalone container itself or the equipment can be integrated in new or existing buildings. In a mobile environment, space is the limiting factor and therefore it is not possible to have more then four people training at the same time. Within a container and a room system, the configuration can handle up to 30 athletes. This limitation exists because of missing data for bigger air conditioning systems. In general, the NHT is designed for a maximum height of 4500 meters, as training above that altitude would require prior acclimatization.

Chamber Type	Mobile	Container	Building
Number Athletes	up to 4	up to 30	up to 30
Set Up Time	30 min	less then 30 min	
Training Altitude	up to 4500 m		

Table 10: Limiting Parameters in Relation to Chamber Type

In the process of finding the right product variant to serve the customer, there are more inputs necessary. The system mainly is dependent on the number of athletes and the minimum room size could also be calculated from this metric. Additionally the base level altitude, the training equipment, the real room size are needed, just to name a few.

5.2.2 Input Parameters

In order to improve usability, the inputs are categorized into *chamber design*, *environment*, *training equipment*, *training room* and *travel costs* related. The chamber design includes the size and type of the training room, whereas the environmental conditions are summarized in a separate category. To determine if the preferred training room is suitable, for the desired equipment has to be known. Lastly, the category for travel costs was included because it is dependent on the county where the system is installed.

Chamber Design

The first input parameter, displayed in figure 33, is the *Chamber Type*. The customer can choose between a system in a building, standalone container or on the backside of a truck as a mobile system. The building offers the most variability and the container relies on predefined configurations. For the mobile system, there is just one size that fits four athletes because of legal regulations for structures on trucks.

The next metric the customer has to think about is the *Number of Athletes*. This number determines for how many athletes the nitrogen system is designed and it can range from zero to 30 athletes with the deposited data. The second number is related to the additional *Number of Sleep Stations* the chamber system has. There is a differentiation between these two numbers, because an athlete needs additional training equipment and more oxygen, whereas for rehabilitation, less nitrogen and no special equipment are needed.

For bigger training facilities, the parameter *Number of Training Rooms* can be used. By default, this parameter is set to one, but with the NHT it is possible to operate several training rooms simultaneously at different altitudes. The *Number of Sleeping Rooms* can be set if separate sleeping or rehabilitation rooms are needed. When the training rooms are not fully utilized, they can also be used for recovery purposes.

The nitrogen system is always dimensioned to reach 4500 meters in a maximum of 30 minutes. Additionally, this *Set Up Time* can be upgraded to be twice as fast with the *Upgrade Factor*.

The parameter *Simultaneous Operation* parameter determines whether the rehabilitation rooms and training rooms are operated at the same time and therefore if more nitrogen is needed. In figure 33 the input mask is shown.

Chamber Design			
Chamber Type	**Building**		*Building, Container or Mobile*
Number of Athletes	**4**		*may not exceed 30 athletes*
Number of Sleep Stations	**0**		*may not exceed 30 stations*
Number of Training Rooms	**1**		
Number of Sleep Rooms	**0**		
Set-Up Time for Training	**regular**		*standard is 30 minutes*
Upgrade Factor	**100**	%	*upgrade up to 200% possible*
Simultanious Operation	**No**		*training and recovery simultaniously*

Figure 33: Inputs Related to Chamber Type, own illustration

Environment

The most important environmental parameter is the *base level* at which the NHT is installed. For mobile systems, the lowest operating level must be used for calculation. By default, the base level is set to zero, but if a training facility is located at 1000 meters above sea level, this means a reduction in the amount of nitrogen is needed and this results in a cheaper system.

To ensure the NHT is operating as intended, the *humidity*, as well as the *lowest* and *highest* operating temperature, need to be considered. The environmental input parameters are displayed in figure 34.

Environment			
Base Level	450	m	*standard is 0 m*
Luftfeuchtigkeit	65	%	*Standard Humitity = 65*
Lowest Temp.	-5	°C	
Highest Temp.	35	°C	

Figure 34: Inputs Related to Environment, own illustration

Training Equipment

In this category, the different types of equipment can be filled into the list on the left side in figure 35. A drop-down dependent in the database helps to make further calculations. New equipment can be added to the list and integrated into the overall calculation. Each piece of equipment has data for a minimum space requirement in order to confirm the training space required. In case of sleeping and recovery stations, the equipment list can also be upgraded.

Training Equipment			
Bike SRM	1	#	*SRM High Performance Ergometer*
Row Concept 2	1	#	*Concept 2 Model D PM5*
Trueform Runner	1	#	*Trueform Low Rider*
Spectra Elite	1	#	*Large Surface Treadmill*
Ercolina	1	#	*Ercolina Arm Pull Sytem*
Sum	5	#	

Figure 35: Training Equipment Input List, own illustration

Training Room

This category serves the purpose to include the room dimensions: *Width*, *Length* and *Height* for further calculations. Dependent on the input *Chamber Type* the correct rows have to be used. If a container system is desired there are already pre-defined inputs available from the supplier's data. A mobile system has no inputs because the parameters are constant and the room system is the most versatile variant of the NHT. To calculate with more than one room, the total room size needs to be inputted.

Training Room			
Container Width	2,43	m	1, 2, or 3 Containers alligned
Container Length	5	m	
Container Height	2,7	m	*2,7 m suggested*
Room Width	3	m	
Room Length	4	m	
Room Height	3	m	
Mobile Width	2,30	m	*Standard for Mobile System*
Mobile Length	4,90	m	*Standard for Mobile System*
Mobile Height	2,70	m	*Standard for Mobile System*

Figure 36: Input for Room Size, own illustration

5.2.3 Calculation of Variants

The steps in the calculation are portrayed in this section. Firstly, the *Atmosphere* with O_2 and N_2 required attention because it is dependent on the base level. The *Nitrogen* system is primarily dependent on the number of athletes but also changes slightly if the base level is altered.

In addition, the *Equipment* cost and *Required Room Size* is calculated. For the *Air-Conditioning*, just an estimation is included because suppliers did not provide the exact data. Furthermore, costs are split up into the categories of *Material*, *Personnel*, *External* and *Travel Costs*. The category of *Other Cost* is included to consider special cases.

Atmosphere Calculation

The fraction of inspired oxygen and nitrogen in natural altitude remains the same up to an altitude of around 11.000 meters. The atmosphere contains 21 % O_2 and 78 % of N_2 (Domej & Schwaberger, 2015b, p. 290). This equals a nitrogen pressure of 593 mmHg. To simulate normobaric hypoxic altitude the air is enriched with nitrogen that replaces the oxygen in the air. To simulate 4500 meters above sea level, just 11,3 % O_2, but 87,7 % N_2 is needed. This nitrogen amount equals a pressure of 666 mmHg. In figure 37 the development with nitrogen and oxygen can be seen in relation to the altitude. For the natural atmosphere, the oxygen and nitrogen relation stays the same whereas the amounts have to shift in artificial atmosphere because the overall pressure is not diminished.

The base level input is necessary to adjust this calculation in the absolute amount of nitrogen needed. At a base level of 1000 meters, the N_2 amount to simulate 4500 meters drops from 87,7

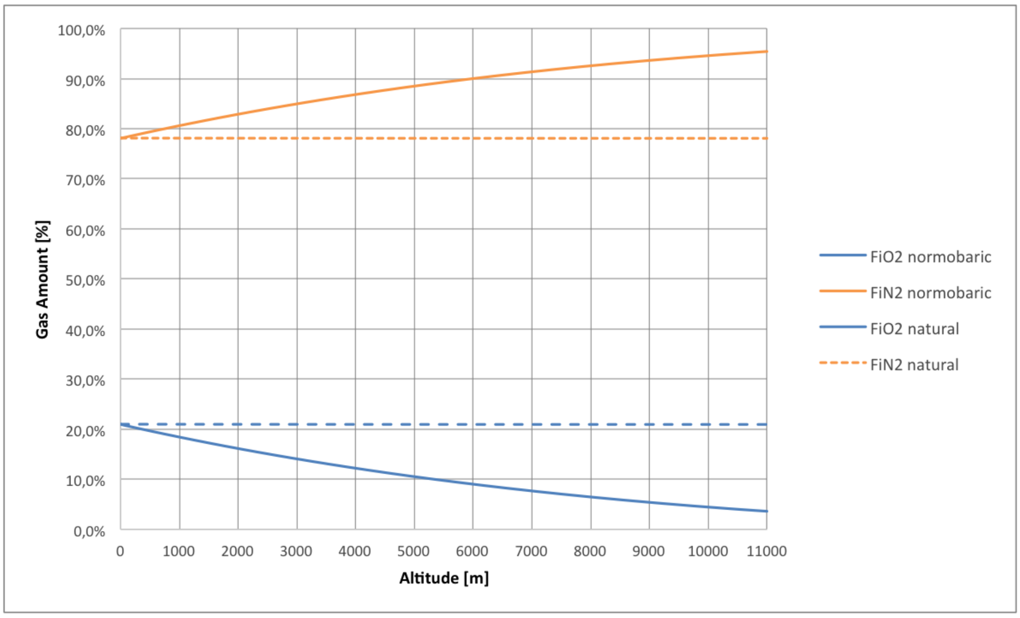


Figure 37: Nitrogen and Oxygen Amount Dependent on Altitude, own illustration

% to 86,1 %. The nitrogen pressure at 1000 meters is 526 mmHg (78,1 %) and to simulate 4500 meters, the nitrogen pressure just has to be 581 mmHg. This results in a pressure change of 55 mmHg instead of 73 mmHg when at sea level and therefore around 25 % less work for the nitrogen system to simulate the same altitude. In figure 38 the dependence of nitrogen and base level is displayed in a graph.

This means the higher the base altitude, the less nitrogen is needed to simulate training at 4500 meters. Furthermore, it means that with a fixed nitrogen amount, an altitude level relative to the base level can be reached. If the chamber needs to be on a stable altitude of 4500 meters the nitrogen fraction is dependent on the location of the chamber. If the location changes, the chamber system needs recalibration.

Calculation of Nitrogen

To calculate the nitrogen system, the main parameter is the number of athletes. If the sleeping stations are used during training time, the nitrogen amount needs to be equated to be prepared for the higher demand.

Rudolf Gann from AMST supported a simulation in order to estimate the nitrogen as a function of the number of athletes. In figure 39 that curve is plotted and a nearly linear and therefore

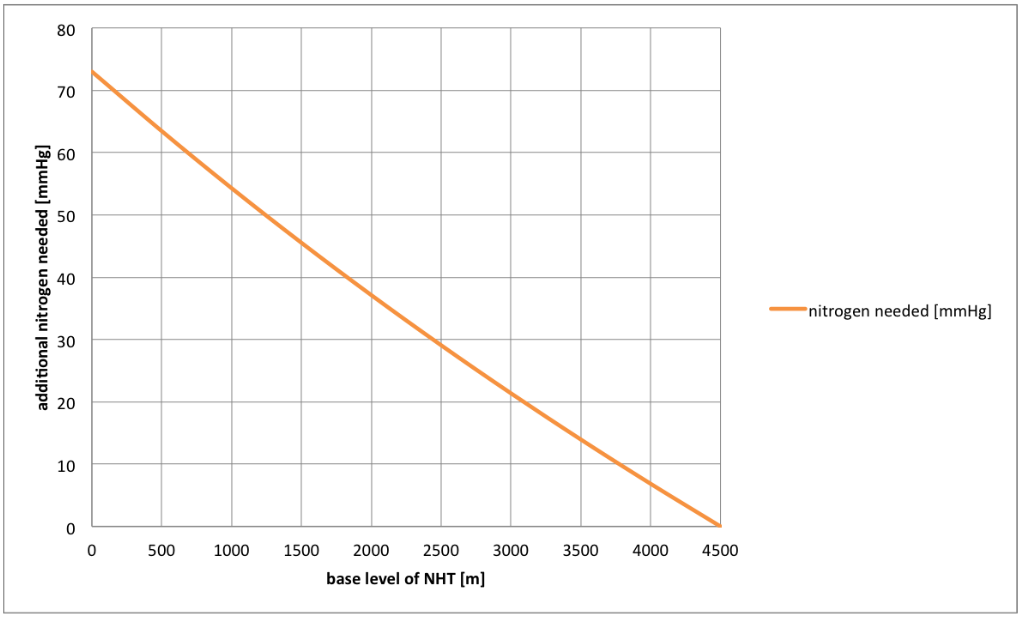


Figure 38: Nitrogen Dependent on Base Level, own illustration

easy to implement metric is found. The nitrogen volume flow rate for each athlete training increases by 16 m^3/h and for a recovering athlete by 6 m^3/h. This metric is tested but it can need further adjustment for different chamber types due to losses.

Furthermore, the base level is taken into account to get a more realistic value. If the customer decides to change the set up time, then this will also change the nitrogen volume flow rate. In figure 40 the calculation for the nitrogen system including the compressed air system can be seen. After the necessary amount is calculated, the configurator chooses the appropriate nitrogen sytem and calculates the compressed air system needed. Because there are different types it can never precisely achieve the exact amount needed. The system will always be over dimensioned and this can be seen in the calculated set up time, which will always be below 30 minutes, as it was the standard time for the simulation done.

The relevant input parameter for calculation in figure 40 includes the base level at 400 meters, four athletes and two sleep stations, operated simultaneously and a slightly upgrade factor of 120 %. This results in the nitrogen system IMN MN 1350 with a nitrogen capacity of 100 cubic meters per hour and the compressor type RS 1-30. The set up time will be 22 minutes and the cost for nitrogen system, including compressed air supply, account for 65.405 Euro.

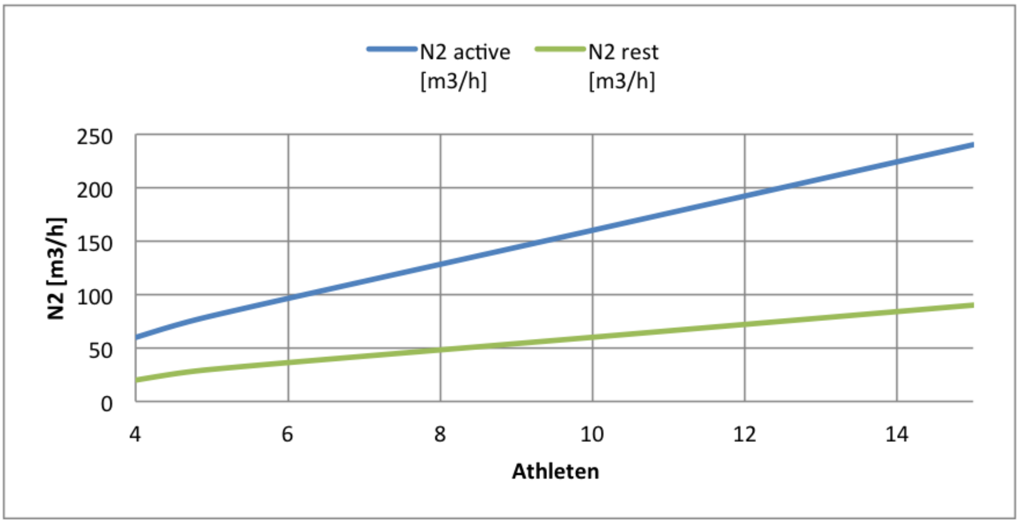


Figure 39: Nitrogen Amount for Athletes and Sleep Stations, own illustration

Calculation Training Room Size

The input needed to calculate training room size is primarily the equipment (figure 35). Each piece of equipment has a different space requirement. For example, the SRM bike ergometer needs 2,4 x 1,1 meters in space, whereas the Spectra Elite treadmill is more space consuming, requiring at least 3,0 x 1,5 meters. The different space requirements can be looked up in the register equipment in the configuration file. The database can be upgraded with new equipment and space requirements. It is suggested that the amount of training devices meets the number of athletes for calculation.

After the required area is defined, the chosen training room is checked for sufficient space. In case a mobile system is desired, it will always be a special container with a defined size. For the chamber type building, the measurements for the room size are freely definable and for container solutions, drop-downs are limiting to available variants from BOX&BOX. A container can be as small as 2,43 x 2,43 x 2,7 meters (width x length x height) and the maximum size is 7,26 x 12 x 2,7 meters. The small version is suggested for no more than two athletes, and the largest version can serve around 30 athletes comfortably training at the same time.

Cost Calculation

In the cost calculation the material as well as the personnel costs are listed. Additionally external cost, travel costs and other costs are included. Each type of cost is calculated in its own register in the configuration file. The calculation includes the AMST related Work Breakdown Structure

Nitrogen System			
Base Level Pressure	724,65	mmHg	*air pressure at base level*
$PiN_{2\ \text{(4500 m, base at X)}}$	631,13	mmHg	*nitrogen pressure to simulate 4500 meters*
Nitrogen Factor für Base Level	0,947		*factor to consider base level*
Volume Athletes	60,6	m^3/h	*nitrogen required for athletes*
Volume Sleep Stations	11,4	m^3/h	*nitrogen required for sleep stations*
Simultanious Operation	1	1 = Yes	*training and recovery operating*
N_2 Minimum	72,0	m^3/h	*minimum required nitrogen amount*
Upgrade Factor	1,2		*upgrade factor for set up time*
N_2 Needed	86,4	m^3/h	*nitrogen amount for further calculation*
Nitrogen System Type	IMT MN 1350		*nitrogen system from Imnatec*
Nitrogen System Cost	41.010,00	€	*cost nitrogen system*
N_2 Capacity	100	m^3/h	*nitrogen installed*
N_2 Utilization	72	%	*utilization of nitrogen system*
Compressed Air required	260	m^3/h	*compressed air for operation*
Compressor System Type	RS 1-30		*compresses air system from Renner*
Compressor System Cost	24.395,00	€	*cost compressed air system*
Compressor Capacity	262,8	m^3/h	*compressed air installed*
Compressor Utilization	99	%	*compressed air utilization*
Calculated Set Up Time	22	min	*calculated from installed nitrogen system*

Figure 40: Nitrogen Calculation, own illustration

(WBS) with the work package description as well as the actual costs depending on the input. The personnel costs additionally include the cost center that tells in which department the cost occur. Costs are either fixed or variable and dependent on the given input. The register with material cost can also serve as a bill of material because the quantities are included. In the overall cost calculation register, the different types of costs are summarized according to their WBS.

In the two pie charts in figure 41, the cost relations with two different configurations are shown as an example. The left chart displays the relation of production costs for four athletes. In this scenario the personnel cost exceed the material cost because even for smaller systems, some research and development needs to be done. On the left side, the result for 16 athletes shows a smaller relation of personnel costs. In the next section some scenarios are explained and the prices compared.

5.3 Cost Calculation and Results

In this section the results of the configuration file are analyzed. Therefore different variants are compared and the calculation results displayed. At first, a minimum and a standard configuration are defined and compared. Then there is a comparison between the different chamber types and finally a curve for production cost development is generated, dependent on the number of athletes.

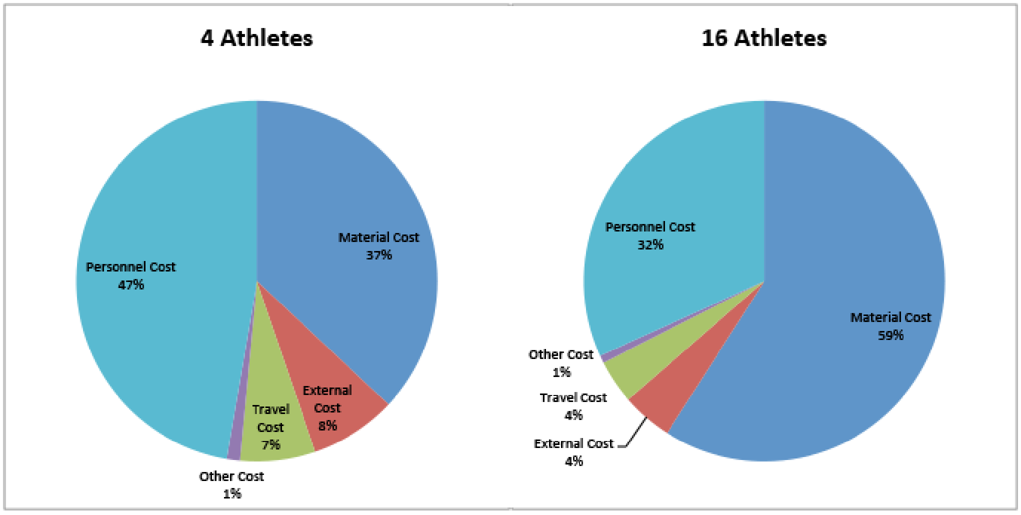


Figure 41: Relation of Production Costs dependent on Athletes, own illustration

Further detailed information about the calculations can be found in the configuration file.

5.3.1 Minimum Configuration

Because material costs for the NHT roughly contribute to the half of the costs in this minimum configuration, the training equipment is left out in order to simulate altitude and does not include training analysis systems.

The input parameters concerning this minimum configuration are found in table 11. With these parameters, the most cost saving variant is calculated without missing the important comfort of altitude regulation, air conditioning and illumination. This variant is limited to four athletes with the assumption that an existing infrastructure of a building is used. Further assumptions are that only one room is used for training and recovery with the area of 12.5 square meters, located in Graz, at 400 meters above sea level. The room size for calculation was determined because it is comparable to a container as well as a mobile variant.

Material Cost

The big cost drivers on the material side are the nitrogen system, air-conditioning system, the sensors, spare parts, power distribution and illumination that are listed in table 12. This totals in 105.706,- Euros in material costs.

Description	Value	Remark
Chamber Type	Building	integrated in existing infrastructure
Number of Athletes	4	smallest nitrogen system from database
Number of Sleep Stations	0	usage of training room for recovery
Number of Training Rooms	1	one multi-purpose room
Number of Sleep Rooms	0	the training room is used
Set-Up Time for Training	regular	
Upgrade Factor	100	this is the standard
Simultaneous Operation	No	training or rehabilitation is done
Base Level	400 m	located in Graz
Humidity	65 %	standard
Lowest Temp.	-5 C	standard
Highest Temp.	35 C	standard
Training equipment	no	in order to safe costs
Room Width	2,5 m	for comparison to other chamber types
Room Length	5 m	
Room Height	3 m	
Travel Costs	Western Europe	cheapest

Table 11: Inputs for Minimum Configuration

The cost of 52.156,- Euro for the *nitrogen system* includes the IMN MN 1250 membrane gas system with the necessary compressed air system, RS 18.5. *Spare parts* are necessary and the 16.000,- Euros are assumed as fixed cost for each variant of the NHT system.

The price for *air-conditioning* is estimated for a room size of 37.5 cubic meters. The cost of 13.049,- Euros includes the climatization system, ventilation assembly and cost for pipes and small parts.

Cost for *sensor systems* include a heated oxygen analyzer, carbon dioxide measurement and three moisture and temperature transducers. The *low-voltage power distribution* includes a Programmable Logic Controller (PLC), monitors, cables and small parts. *Illumination* is including a high power LED light for each athlete and the necessary cables and controllers. Because there is no *sports equipment* in this minimum configuration, there are also no material costs for it and the *other costs* are summarizing things such as computer and network systems and standard parts, mainly for installation.

Work-package	Total Cost in EUR	Description
Nitrogen-System	52.156,-	IMT MN 1250
Spare Parts	16.000,-	fixed cost
Air-Conditioning System	13.049,-	37,5 cubic meters
Sensor System	8.771,-	Oxygen, CO_2, Humidity
LV-Power-Distribution	6.481,-	Control and Monitors
Illumination	4.271,-	Lightning and Controls
Sports Equipment	0,-	no equipment for this variant
Others	4.978,-	computer & network system, standard parts
Material Cost	105.706,-	

Table 12: Material Cost Minimum Configuration

Personnel Cost

The cost of working hours are estimated and change with certain inputs. For the minimum configuration, 1300 working hours are assigned to different cost centers. This number is including 300 hours for *research and development* whereof 100 hours are reserved for project management. For *electrical* and *mechanical engineering*, 340 hours are calculated. For *software development* and *documentation*, 180 hours respectively are taken into account. Each of these numbers can be reduced after the first products are delivered because of scaling effects.

Working hours for *electrical* and *mechanical manufacturing*, as well as *logistics*, are 300 hours in total. These hours cannot be reduced in the future and are scaling up with the size of the NHT because the work needs to be done at every configuration. Each cost center has a different hourly rate, and with this consideration, the result in total personnel cost is 136.939,- Euro for the minimum configuration.

Production Cost

The production cost for the minimum configuration is displayed in figure 41, with the material and the personnel cost being the main cost drivers. *External cost*, mainly including the professional sport instruction from European Sports, accounts for 22.500,- Euros. These costs are fixed and do not change with the chamber configuration. *Travel cost* for western Europe accounts for 19.500,- Euros and *other costs* including design reviews and the factory acceptance test amount to 3.400,- Euros. In figure 42 the costs for the minimum configuration are displayed and the sum is **288.045,-** Euros.

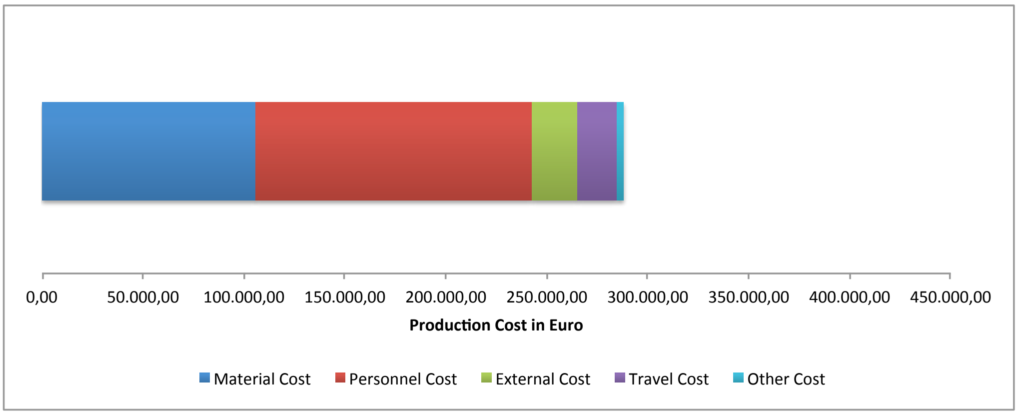


Figure 42: Minimum Cost: 4 Athletes, Building, no Training Equipment; own illustration

5.3.2 Standard Configuration

The standard configuration is very similar to the minimum configuration with the inputs in table 11. The parameter chamber type is set to "container" and the training equipment is included. The training equipment consists of two bikes from SRM, one large surface treadmill from Spectra Elita and one arm pull system from Ercolina.

Material Cost

Therefore the cost of *nitrogen-system*, *spare parts*, *air-conditioning*, *sensor system*, *low voltage power distribution* and *illumination* do not change because the number of athletes and the room size remains the same as for the minimum configuration. In table 13 the new cost driver is the sports equipment and the container system with the adaptations that need to be done. These two positions account for additional costs of 99.533,- Euros. The container needs isolation and preparation in order to have comfortable training conditions and this results in 206.815,- Euros total material cost, which is nearly double the cost as for the minimum configuration.

Personnel Cost

The standard configuration needs slightly more work than the minimum configuration. Because of the sports equipment, 120 additional hours for software development and 80 hours for installation of the equipment need to be accounted for. In sum, the 1500 working hours cause personnel cost of 159.189,- Euros for the standard configuration. In comparison, the minimum configuration is

Work-package	Total Cost in EUR	Description
Nitrogen-System	52.156,-	IMT MN 1250
Spare Parts	16.000,-	fixed cost
Air-Conditioning System	13.049,-	34 cubic meters
Sensor System	8.771,-	Oxygen, CO_2, Humidity
LV-Power-Distribution	7.103,-	Control and Monitors
Illumination	4.271,-	Lightning and Controls
Sports Equipment	66.500,-	2x SRM, 1x Spectra Elite, 1 Ercolina
Container-Vehicle	33.033,-	Container Sytem
Others	5.941,-	
Material Cost	206.815,-	

Table 13: Material Cost Standards Configuration

calculated with 1300 working hours and 136.939,- Euros in total.

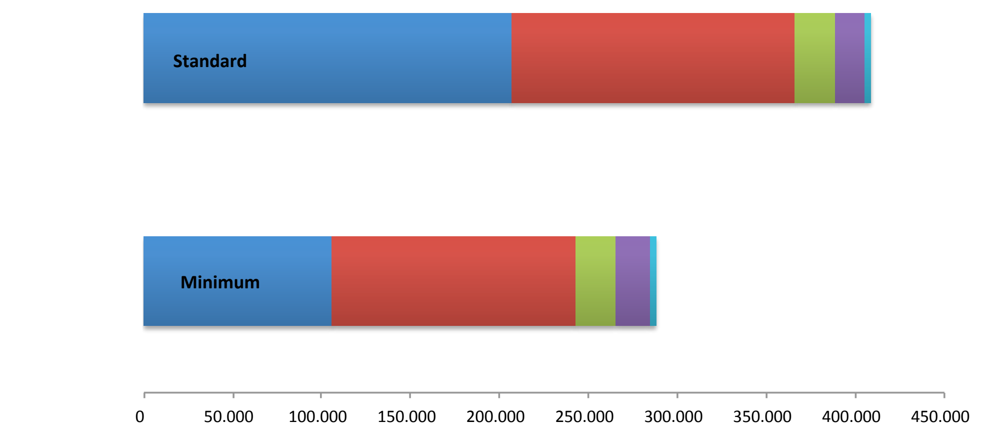
Production Cost

External costs, *travel costs* and *other costs* do not change between the minimum and the standard variant of the NHT system. In figure 43 the differences in cost between the minimum and standard configuration is displayed. The standard configuration for 4 athletes has production costs of **408.684,-** Euros, whereas the minimum configuration results in **288.045,-** Euros.

The additional cost mainly comes from the training equipment, with two SRM Bikes, one Spectra Elite large surface treadmill and the arm pull system from Ercolina. Despite the higher price, it is the standard configuration that has the clear advantage for professional training to be planned, performed and monitored with this holistic solution.

5.3.3 Cost Development

Training equipment is a big cost driver and therefore it is distinguished between the two configuration variants. In figure 44 the price differences between the chamber types with either minimum or standard configuration are displayed.



	Minimum	Standard
Material Cost	105.707	206.815
Personnel Cost	136.939	159.189
External Cost	22.500	22.500
Travel Cost	19.500	16.780
Other Cost	3.400	3.400

Production Cost in Euro

Figure 43: Comparison of Minimum and Standard Configuration: 4 Athletes, own illustration

Comparison of Chamber Types

The input for this configurations is the same as for the minimum configuration from table 11. On the left side in figure 44, the costs for the three chamber types without training equipment are displayed. In the same figure, on the right side, are the production costs for standard configurations, including training equipment.

A solution within an existing building has the same value for the customer than a container solution. Additional value is generated with the mobile system because the location can be changed easily, whereas a container system is also transportable but the effort is higher. The possibilities with a mobile system include on-site training at competitions or the escort of athletes that need to travel the country and this is why the slightly higher costs can be justified.

Due to equipment cost for four athletes, the standard configuration costs are of approximately 90.000,- Eurs more than the minimum configuration. The container system has around 10 percent higher production cost then the building system. To build a container as a mobile system on the backside of a truck increases the price an additional 25 percent.

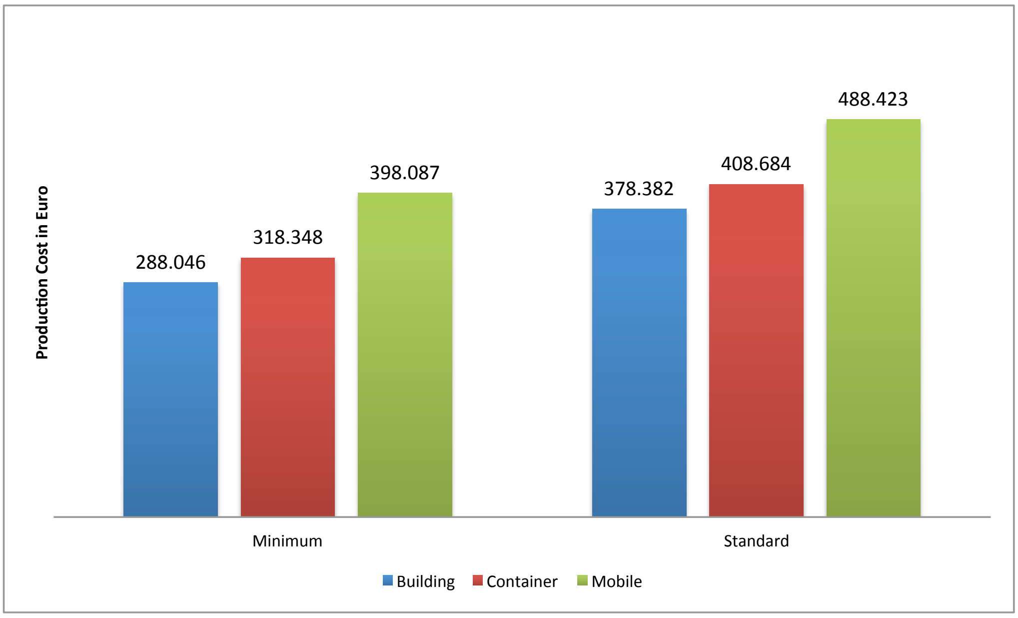


Figure 44: Comparison of Different Chamber Types; Left: Minimum Configuration, Right: Standard Configuration, own illustration

Development of Production Cost

In order to display the production cost for bigger training facilities, two scenarios are calculated. The first scenario assumes an existing facility with increasing number of athletes and the second scenario assumes a container system with either one, two or three containers.

The container size was chosen in order to reach the same utilization with each number of athletes and the room size was adapted to have the same size as the container to obtain comparable numbers. Therefore every athlete was provided approximately 3 square meters of training space. In figure 45, the blue line shows the production cost for the chamber type *building* and the red lines are showing the costs for the *container* system.

As previously mentioned, the training equipment constitutes a big part of the production costs and for an increasing number of athletes, even more equipment needs to be considered. This is why in these two scenarios, the equipment was not included and purely minimum configurations are compared to make the result easier to interpret.

The result in figure 45 shows steps at certain numbers of athletes for both the building and the container systems. These steps occur because at these points, the nitrogen system, the compressed air system or both need an upgraded to the next size. For example it does not matter if the customer

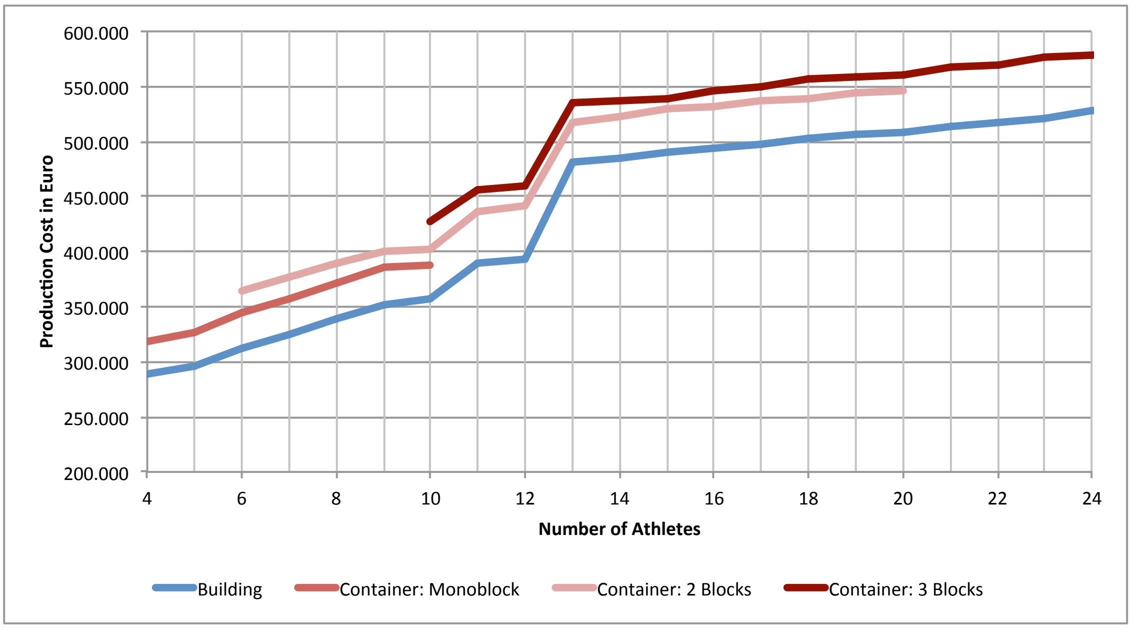


Figure 45: Production Cost Development of NHT, own illustration

orders a system for 11 or 12 athletes because the price is relatively similar. However, for 13 athletes, a bigger nitrogen supply as well as a bigger compressed air supply is needed which tremendously increases the price for this additional athlete. When a container system is desired, it matters whether one, two or three containers are used. A system with two container blocks starts to make sense for more than eight athletes and a system with three containers should be considered if the number of athletes exceeds 20.

With these scenarios and the comparison of the chamber types for four athletes with minimum and standard configuration, it is possible to gain a good overview of the price development of the NHT system. Specific calculations can be found within the Excel file.

6 Concluding Remarks

From the confrontation with literature about innovation and business models, a detailed overview of the most common tools was acquired. The business model canvas from Osterwalder & Pigneur is a straightforward, but holistic tool for the generation of new, or analysis of existing business models. The predefined patterns from Gassmann et al. that are characterized trough four dimensions, which are similar to the elements of the business model canvas, serve as a good inspiration for someone's own business model.

The extent of a product development process is dependent on the complexity of the product. Nonetheless, the main process steps of planning, research and development, concept development, concept design, design, and documentation appear to stay consistent in most processes. Different methods to develop modular products also exist and the Modular Function Deployment (MFD) has been used to support the configuration development. The MFD was supported by the generated business model and a Quality Function Deployment (QFD) to clarify the customers' requirements. The technical solutions were outlined and membrane gas separation is going to be used to produce nitrogen that is mixed with air to reach the desired oxygen concentrations.

The necessary nitrogen amount in relation to the athletes has been implemented into the product configuration and linked with the Microsoft Excel database of nitrogen systems. This configuration file now can be used as the initial step when a customer is asking for an NHT system. On the one hand, the product configuration is limiting in a way to help the customer define his needs, yet on the other hand, it offers enough variability to serve even the most specific demands. The tool is additionally helping sales to gather and provide necessary information, such as the production cost or the type of necessary nitrogen system. This supports further processing in case of purchase.

The Excel tool is easy to use and requires no instruction, because the cost calculation has been adapted to AMST standard cost centers and work package descriptions have been included; it should consequently be self-explanatory. The configuration file can calculate variants ranging from mobile solutions for four athletes, to building or container systems up to 30 athletes and the maximum simulated altitude is 4500 meters above sea level. In figure 46 a design concept of an NHT container system from AMST is shown.

Figure 46: Design Concept of Container System (AMST, 2016a)

6.1 Outlook

The development of a modularization system for the NHT has shown the potential entry into a new civil market. Sophisticated athletes of different levels have similar demands in terms of training to pilots. Next to centrifuge systems, flight simulators, underwater escape training systems, hypobaric chamber, rapid decompression chambers and pilot sports equipment, the Normobaric High Altitude Training fits appropriately as a new product within the AMST product range. Furthermore, the NHT offers the possibility to gain knowledge with modular production concepts, which can result in better order processing and reduced development costs in the long term.

With the existing modularization concept, it is possible to divide the development costs and reduce the production costs which should help to sell more units. Furthermore, the continuous improvement of the business model should help to boost sales as it is possible to deliver the value proposition to the customers segments more efficiently.

During the research on high-altitude training, it was recognized that the real potential of high altitude training is not really known. The NHT system could be used to promote research in the field of sports science and medicine and generate a knowledge base for Intermittent Hypoxia training sessions. With controlled research under reproducible conditions and the help of AMST, future athletes could gain an impressive leap ahead in competition with the world's best athletes.

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