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Cost Assessment and Optimization in the Front-End of the Design and Development Process of a Motorcycle Engine

Diploma Thesis

Mechanical Engineering and Business Economics

Production Science and Management

Graz University of Technology

Faculty of Mechanical Engineering and Economic Sciences

Institute of Industrial Management and Innovation Research

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Statutory Declaration

I declare that I have authored this thesis independently, that I have not used resources other than the declared sources / resources and that I have explicitly marked all material, which has been quoted, either literally or by content, from the used sources.

Graz, ……………………………… ………………………………

(Signature)

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Abstract

The diploma thesis entitled “Cost Assessment and Optimization in the Front-End of the Design and Development Process of a Motorcycle Engine” deals with the practical application of the method Value Analysis in an international product development project. The Research Institute for Internal Combustion Engines and Thermodynamics Ltd. accepted a bid to design and develop a new motorcycle engine. The project includes four basic tasks. These are the layout and design of a 150cc four-stroke motorcycle engine, manufacturing of prototype engines, test bench development of prototype engines and engine and vehicle durability testing. The diploma thesis is implemented in the layout and design phase of the project.

The method Value Analysis, with its systematic, holistic and value-based management approach, provides the basis for the optimization of selected components of a motorcycle engine in terms of functionality and cost. First, with the application of an ABC Analysis, the most valuable parts of the motorcycle engine are filtered out. The cylinder head assembly is selected according to the result of the ABC Analysis and then subjected to Value Analysis. The new designed parts are optimized and compared with an existing engine for benchmarking reasons.

The core element of Value Analysis is the Functional Analysis. The process of Functional Analysis is used to obtain a complete description of the functions of the cylinder head assembly and their relationships, which are systematically represented in a function tree. Afterwards, the function carrier costs of the cylinder head assembly are allocated to the functions and illustrated in a function cost matrix. Subsequently, for all functions, the degree of functional performance is evaluated according to the given requirements. The result is the target cost of the new designed cylinder head assembly of the motorcycle engine.

To achieve the determined target cost and satisfy all customer requirements at the same time, a global solution concept is developed. Finally, various ideas that are integrated in the new design of the cylinder head assembly are presented and the respective estimated cost is compared with the evaluated target cost.

Kurzfassung

Die Diplomarbeit mit dem Titel "Cost Assessment and Optimization in der Front-End of the Design and Development Process of a Motorcycle Engine" befasst sich mit der praktischen Anwendung der Methode Wertanalyse in einem internationalen Entwicklungsprojekt. Die Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH erhielt den Auftrag einen neuen Motorradmotor zu entwerfen und zu entwickeln. Das gesamte Projekt umfasst vier grundlegende Aufgaben: das Layout und Design eines $150cm^3$ Viertakt-Motorradmotors, die Herstellung von Prototypen, die Prüfstandsentwicklung und die Dauerhaltbarkeitsprüfung von Prototyp-Motor und Fahrzeug. Diese Diplomarbeit ist in die Layout- und Design-Phase des Projektes integriert.

Die Wertanalyse bildet mit ihrem systematischen, ganzheitlichen und wertorientierten Ansatz die Grundlage für die Optimierung ausgewählter Komponenten eines Motorradmotors in Bezug auf Funktionalität und Kosten. Zuerst werden mit Hilfe einer ABC-Analyse die kostenintensivsten Teile eines Motorradmotors eruiert. Gemäß dem Ergebnis der ABC-Analyse wird die gesamte Zylinderkopfbaugruppe als Untersuchungsobjekt ausgewählt und in weiterer Folge einer Wertanalyse unterzogen. Dabei werden die neu gestalteten Bauteile optimiert und mit den Komponenten eines Referenzmotors für Benchmarking Zwecke verglichen.

Das Herzstück der Wertanalyse ist die Funktionenanalyse. Die Funktionenanalyse ist notwendig um eine vollständige funktionale Beschreibung der Zylinderkopfgruppe auf- und ihre Beziehungen untereinander systematisch darzustellen. Anschließend werden die Funktionsträgerkosten der Zylinderkopfbaugruppe auf die Funktionen übertragen und in einer Funktionen-Kosten-Matrix dargestellt. Alle Funktionen werden unter Berücksichtigung der Kundenanforderungen hinsichtlich ihres Funktionserfüllungsgrades bewertet. Das Ergebnis sind die Zielkosten der neu entwickelten Zylinderkopfgruppe des Motorradmotors.

Um die errechneten Zielkosten zu erreichen und gleichzeitig allen Anforderungen des Kunden zu entsprechen, wird eine gesamtheitliches Lösungskonzept entwickelt. Die verschiedenen Ideen, die im neuen Design der Zylinderkopfgruppe integriert sind, werden vorgestellt und die entsprechenden Kosten mit den im Vorhinein ermittelten Zielkosten verglichen.

Table of Contents

1 Introduction and Problem Statement

The diploma thesis at hand deals with the practical application of the method Value Analysis (VA) in an international product development project. Chapter one describes the initial situation and stakes out the framework for the diploma thesis. Furthermore, the problem statement and the general objectives are presented. At the end of chapter one, how the work on the topic is structured is explained.

1.1 Initial Situation

The Research Institute for Internal Combustion Engines and Thermodynamics Ltd. (FVT) accepted a bid to design and develop a new motorcycle engine. The project started in May 2012 and included the following basic tasks:[1]

- Layout and design of a 150cc four-stroke motorcycle engine:
  - Four valves
  - Single Overhead Camshaft (SOHC)
  - Water-cooled
  - Six-speed gearbox with semi automatic shifting
- Electronic fuel injection (EFI)
- Manufacturing of prototype engines
- Test bench development of prototype engine
- Engine and vehicle durability testing

This diploma thesis is implemented in the layout and design phase of the project.

Research Institute for Internal Combustion Engines and Thermodynamics Ltd.

The Research Institute for Internal Combustion Engines and Thermodynamics Ltd. (FVT) was founded in 2002 by the management of the Institute for Internal Combustion Engines and Thermodynamics (IVT), at Graz University of Technology (TUG). FVT's work is closely linked to IVT's work. Since September 2002, a cooperation agreement exists between FVT and TUG, in the field of research and development projects with third parties.[2]

[1] Cf. FVT (2012a), p.4
[2] Cf. http://fvt.tugraz.at, date of access: 8.10.2012

Customer

Until the start of the motorcycle engine development project, the customer has not yet developed an engine itself. Actually, the engine is a purchased part and the design of the engine is not state of the art. For this reason, the engine design and development project is very significant for the customer. The newly designed motorcycle engine represents a huge technological leap for the company. Additionally, the customer enlarges its own product range with a modular design of the new engine.

Collaboration

The new motorcycle engine will be the first one produced by the customer. The aim is that employees of the customer support the engineers from FVT in the design and development process. Thus, the customer wishes to gain knowledge on how to build up a new motorcycle engine. For better collaboration, some engineers of the customer are working in Graz throughout the entire duration of the project until it ends in March 2015. They are also responsible for the communication between the headquarters of the customer and the engineers from FVT. This makes it possible to exchange information quite fast so it is easier to stay within the project timeline.

1.2 Assignment of Tasks

The main aim of this diploma thesis is to optimize design and costs of selected components of the engine by implementing the method Value Analysis (VA). For this challenge, a particular project team, with internal and external members, will be formed. Several workshops and discussions with the project team will ensure that the know-how and experience of all members is considered in the design process. After the identification of potential savings and comparison of possible solutions, the best concepts are integrated into the final product.

One additional part of the work is the cost estimation of the newly designed motorcycle engine. Also, a comparison with the existing benchmark engine is required. Within the diploma project there are two milestones:

- Up until the freezing of the basic engine layout in October 2012, the Bill of Material (BOM) cost estimation for the proposed concept and a comparison with the existing benchmark engine is required.
- A detailed BOM cost analysis for the new engine is required at finalization of the engine design and start of prototype manufacturing in January 2013.

XY150

The name of the new motorcycle engine is XY150. XY stands for customer “XY” and “150” for the basic model of the engine, with the displacement of 150cc. One of the key requirements of the customer for the development of the new engine is the integration of a modular design. This offers the possibility to use the basic engine for three models with different displacements (125cc, 150cc, 175cc). The different power of the three engines is achieved by replacing the cylinder block and piston, while all other components remain the same. This means, for example, that the cylinder head has to be designed in a way that it is suitable for all three models. Here, the calculations for the stresses are done for the most powerful engine (175cc). The design for the most efficient operation and minimal energy consumption is made for the 150cc engine and the reference for the geometrical set-up is the displacement with 125cc.

The following list gives an overview of the requirements for the new engine concept:[3]

- Modular design (125cc, 150cc, 175cc)
- Compact and modern engine concept
- Muscular and performance oriented appearance
- High quality appearance
- Easy to manufacture at lowest possible cost
- Reliable and durable for daily use

Further considerations for the design and development process of the new engine are the components. The following points need to be taken into account:[4]

- To utilize as many existing engine components of the customer as possible
- To utilize standard components from reputable suppliers or existing suppliers of the customer.
- To minimize the tooling development for standard parts

Basically, the design and development work should concentrate on the cylinder head and other newly designed components, to optimize the performance and durability of the engine.[5]

[3] Cf. FVT (2012b), p.18
[4] Ibidem
[5] Ibidem

Yamaha YZF125

For Benchmarking, the Yamaha YZF125 was selected due to similar engine specifications and the compact and robust design of the engine.

The layout of the benchmark engine is illustrated in Fig. 1. The benchmark engine is a liquid-cooled, forward-inclinded single cylinder, four-stroke engine with four valves. The controlling of the valves is realised by a single overhead camshaft (SOHC). The fuel (premium unleaded gasoline) is added by a electronic fuel injection system into the intake manifold. The engine has an electric starter and a primary and secondary catalyst.[6]

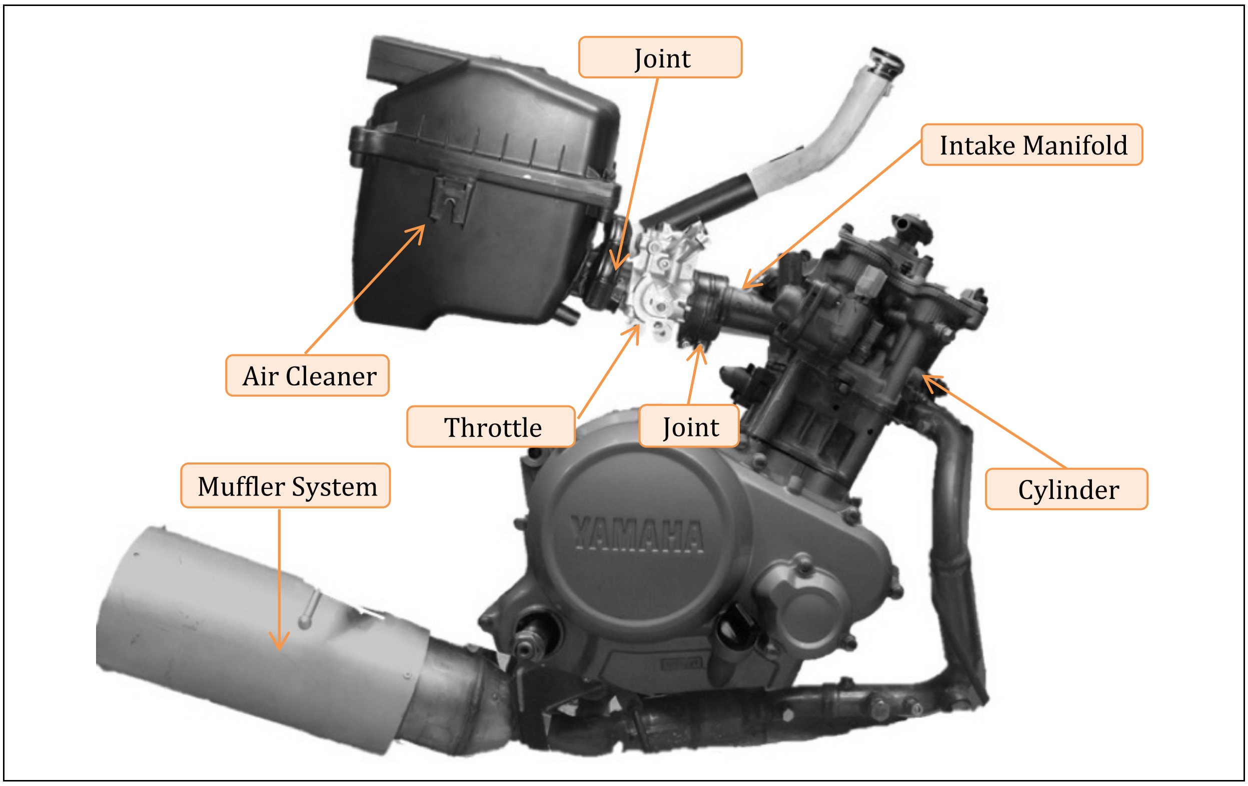

Fig. 1: Layout of Benchmark Engine[7]

For easier comparison, the engine specifications for the XY150 and the Yamaha YZF125 are displayed in Table 1. It can be seen, that the stroke of both engines is the same (58.6mm), while the bore is different. The XY150 requires more power (12kW) and torque (12.5Nm). Also, the required engine speed of the newly designed motorcycle engine is higher than the engine speed of the benchmark model. Highly

[6] Cf. Service Manual YZF-R125 (2008), p.2-2
[7] FVT (2012d), p.6

significant for the design of the engine, is the difference for the required emission standard. The XY150 must reach EURO 5, while the YZF125 only fulfils the EURO 3 norm.

Item	XY150	YZF125
Engine Type	Liquid-cooled, four-stroke, SOHC, four valves	Liquid-cooled, four-stroke, SOHC, four valves
Cylinder	Single	Single
Displacement (cc)	149.8	124.66
Bore (mm) X Stroke (mm)	57.0 X 58.6	52.0 X 58.6
Compression Ratio	11.2 : 1	11.2 : 1
Max. Power	12kW (16.1HP) at 9,800rpm	11.0kW (14.8HP) at 9,000rpm
Max. Torque	12.5Nm at 8,800rpm	12.24Nm at 8,000rpm
Emission	EURO 5	EURO 3

Table 1: Comparison of XY150 and YZF125 Specifications[8]

1.3 Objectives

The aim of this diploma thesis is to optimize design and costs of selected components of a motorcycle engine by implementing the method Value Analysis (VA). After the identification of potential savings and comparison of possible solutions, the best concepts are integrated into the final product.

An additional objective is the implementation of value analytical thinking in the design department of the Institute for Internal Combustion Engines and Thermodynamics. Over the course of this thesis, how the project staff accepted the method Value Analysis and which difficulties occurred during the diploma project are mentioned. Furthermore, possible reasons for problems experienced and approaches for preventing the problems in future projects are stated.

[8] Cf. FVT (2012c), p.33

1.4 Procedural Method

The “Value Analysis” chapter describes the theoretical basics of the method Value Analysis (VA). Important terms and definitions are explained and the work plan according to the EN 12973 is presented. Subsequently, every work step is described in detail. In addition, various management tools and useful techniques, which can be used to accomplish the work steps, are presented and the instruments are linked to their relevant step in the work plan.

Furthermore, chapter two gives an overview on the benefits and disadvantages of VA. Crucial success factors for a VA project are highlighted and the limits of this method are discussed. This section will be closed with an argumentation on why the application of VA is appropriate within the design and development process of the new motorcycle engine.

The third chapter illustrates the practical work within the project team and explains the progress according to the VA work plan. Finally, the results of the VA are presented.

The conclusion presents a summary of the results and the outlook of further improvements for the application of VA in future design and development projects, at the Research Institute for Internal Combustion Engines and Thermodynamics.

1.5 Summary

With the application of the method Value Analysis (VA) to an international product development project, selected components of a motorcycle engine should be optimized to meet customer requirements. Therefore, several workshops, with a particular VA project team, are necessary to identify potential savings and to develop a global concept, which can be applied to the final product.

2 Value Analysis

This chapter presents basic information on the topic of Value Analysis (VA). This method is assumed as the origin of a management approach called Value Management (VM). Today, VA with its systematic, holistic and value-based management approach is one of various methods of VM. The VA can also be used separately. The method itself is explained in the following section, after the description of the basic concepts and relationships.

2.1 Outline

The process of product development has changed drastically in recent years. The main reasons for this are area political and economic changes, such as the enlargement of the European Union's internal market, the opening of Eastern Europe, the immense ambition of China or the global financial crisis. Consequences are the occurrence of highly competitive global markets and the resulting cost pressure, as well as shorter development cycles. One successful approach for coping with these challenges is Value Management (VM) together with the firmly established Value Analysis (VA) as for processing successful projects.[9]

The five characteristics; function concept, value concept, holistic approach, strong involvement of people and their behaviour and interdisciplinary teamwork provide excellent conditions for meeting the requirements of the product development process as well as the product itself. Additionally, VA is a methods system where other tools and management instruments (e.g. Quality Function Deployment, Failure Mode and Effects Analysis) can be integrated at appropriate steps. Thus, VA is a powerful system achieving the specified goals.[10]

2.2 Definition

According to EN 12973 Value Analysis (VA) is defined as *"[…] an organised and creative approach, using a functional and economic design process which aims at increasing the value of a VA subject. The use of VA makes organisations more efficient by improving the competitiveness of their products."*[11]

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[9] Cf. VDI (2011), pp.1-2
[10] Cf. VDI (2011), p.2
[11] EN 12973 (2000), p.25

VA's creative character is clearly expressed by its originator, LAWRENCE D. MILES, who considers the VA as a philosophy in terms of a basic adjustment: *"Value analysis is a philosophy implemented by the use of a specific set of techniques, a body of knowledge and a group of learned skills. It is an organized creative approach, which has for its purpose the efficient identification of unnecessary costs, i.e. costs, which provide neither quality, nor use, nor life, nor appearance, nor customer feature."*[12] From this definition, it is obvious that VA is more than just the terms value and analysis stand for.

The VDI-Directive 2800 defines VA as an effect system for solving complex problems that are not or not fully algorithmic. The definition involves the interaction of the elements method, human factors and management and operating systems, including environmental factors, as contribution to the holistic approach of the VA object.[13]

All VA include the same basic elements. These are the application of a standardized work plan, the use of a function-oriented view of objects and the work with interdisciplinary teams. Special attention is paid to the work plan, as this is the "central theme" of VA.[14]

2.3 Areas of Application

Basically, any type of object can act as a VA object. These objects can be either concrete products or also services and intangible processes. Value analytical thinking and work has been used successfully in the wholesale industry as well as in medium-sized companies in all industries, in sciences and in the public sector. It makes no difference whether the object itself is developed and manufactured, or whether it is purchased. Products can be simple parts or complex assemblies. Processes can be assembly sequences or even complete business processes, such as procurement, logistics, product development and strategy development. If the investigated objects already exist, then the application of VA is called value improvement. On the other hand, if the objects do not already exist, the VA process is called value creation.[15]

But the VA does not claim to be used for every problem statement. Its application must be made in terms of economic efficiency because the use of VA is associated

[12] Miles (1961), p.1
[13] Cf. VDI-Richtlinie 2800 (2000), p.2
[14] Cf. VDI (2011), p.27
[15] Cf. Pauwels (2001), p.33

with considerable effort. This must be reflected in the objectives, so that both costs for the VA study and possible consequential costs (e.g. modification costs) amortise within a manageable time frame. This also means that the object is not at the end of its life cycle. If these conditions are not met, it is necessary to find other ways and methods of increasing the value of the object.[16]

2.4 Selection Criteria

When only considering the deployment of the project team, the Value Analysis (VA) is aligned with relatively high costs. Therefore, it is always advisable to examine how the following selection criteria for VA tasks are fulfilled:[17]

- *Complex task:* Information from different areas is needed, for the accomplishment of the task. Thus, interdisciplinary teamwork is beneficial.
- *Challenging value targets:* The improvements for quantifiable values should not be less than 15 percent. Otherwise, a regular rationalization task, which can be achieved by other methods or the specialized knowledge of an expert, may be more economic.
- *Solution concept does not exist:* VA should not be used for projects that already have a solution. VA is not an "instrument for reviews".
- *More specialized methods are not available:* This criterion does not only depend on the problem itself but also on the knowledge level, the level of education and the creativity of the participants.

It is only worthwhile to use the VA method if all four criteria can be answered positively. In Fig. 2 various selection criteria for the application of VA are summarized.

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[16] Cf. Leitner (2005), p.109
[17] Cf. Zentrum Wertanalyse (1995), p.22

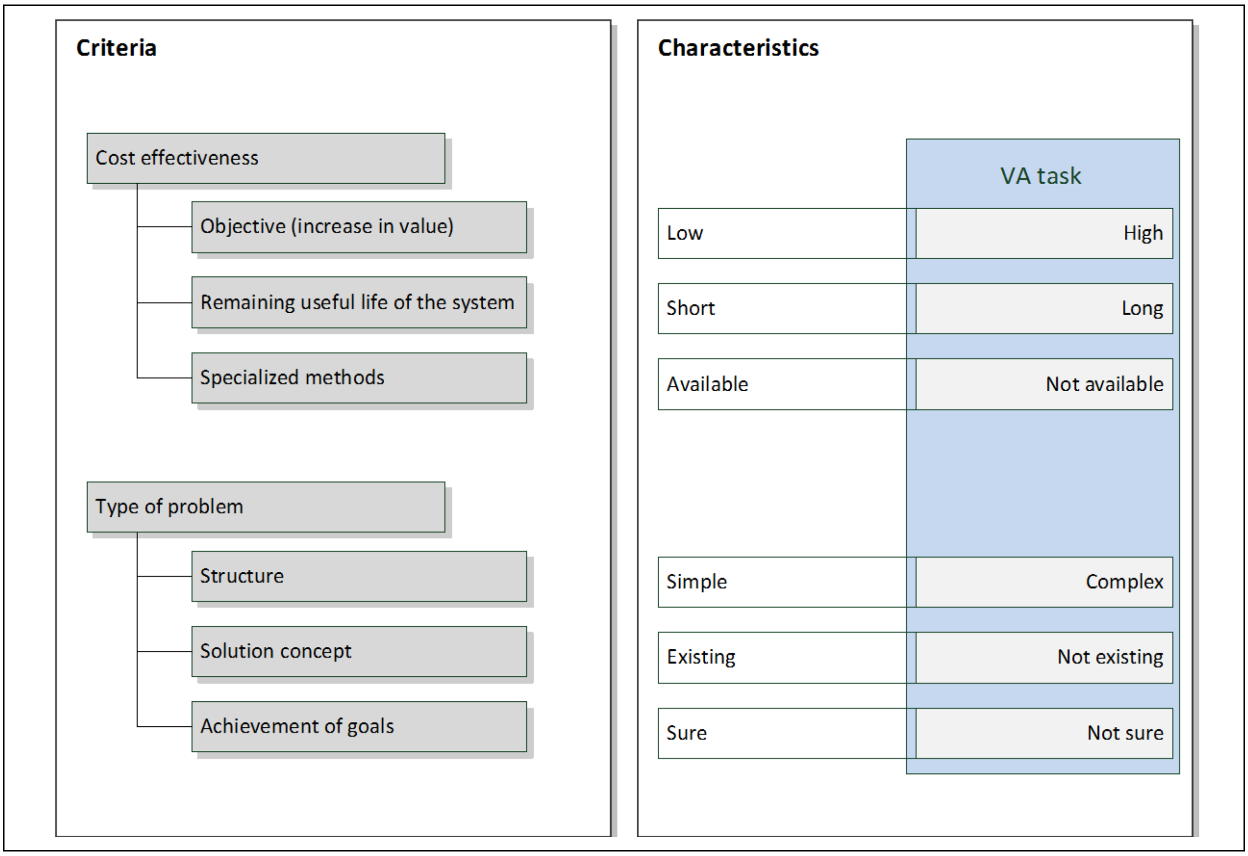

Fig. 2: Selection Criteria for Value Analysis Tasks[18]

2.5 From Value Analysis to Value Management

Value Analysis (VA) originates from immediately after the Second World War. Many materials needed for the production were either scarce, not available at all or too expensive. Back then, LAWRENCE D. MILES was chief purchaser at General Electric (USA) and at that time he was instructed to search for material and activity alternatives. Amazingly, these alternatives often satisfied greater demands than the original solutions and lowered costs. Realizing this, MILES developed a method for achieving the effect of the value improvement not just by chance but intentionally and systematically. In 1947, the method VA was created, in which he combined already known techniques, such as teamwork, functional concepts, analytical techniques and idea generation concepts in a simple work plan.[19]

Initially, the method was only applied to already existing objects of production to reduce costs. Very soon, the potential of this approach was realized and also applied

[18] Cf. Hasenöhrl (1986), p.33
[19] Cf. Zentrum Wertanalyse (1995), pp.10-11

to products, which were still under development. This method was called Value Engineering (VE).[20]

Due to the success of VA and VE, other major American companies implemented the new method. In 1959, the Society of American Value Engineers (SAVE) was established. SAVE aims to develop and spread methods and manages the VA training as well as providing an exchange of experiences of value analysts. In German-speaking countries, the community committee VA of the Association of German Engineers (VDI), who published a VDI-Directive for the methodology (1975), adopted this task. In 1984, the VDI center, VA (ZWA) VDI-GSP, was established with the objective of achieving intensive and systematic development of the VA method and integrating new knowledge into an educational program. In Austria, the Economic Development Institute of the Economic Chamber Austria (WIFI-ZWA) supported VA. Furthermore, this establishment is responsible for the exchange of experiences of value analysts working in Austria.[21]

VA is also used globally as an effective tool for the management, for improving the value of existing products and services and creating value for new products and services.[22]

2.6 Key Principles of Value Management

The difference between Value Management (VM) and other management styles is that there are certain attributes involved simultaneously, which usually cannot be found together. This circumstance contributes to the success of VM.[23] The following section gives an insight into the four attributes of VM, which are also displayed in Fig. 3.

[20] Cf. Wohinz (1983), p.28
[21] Cf. Zentrum Wertanalyse (1995), p.12
[22] Ibidem
[23] Cf. VDI (2011), p.17

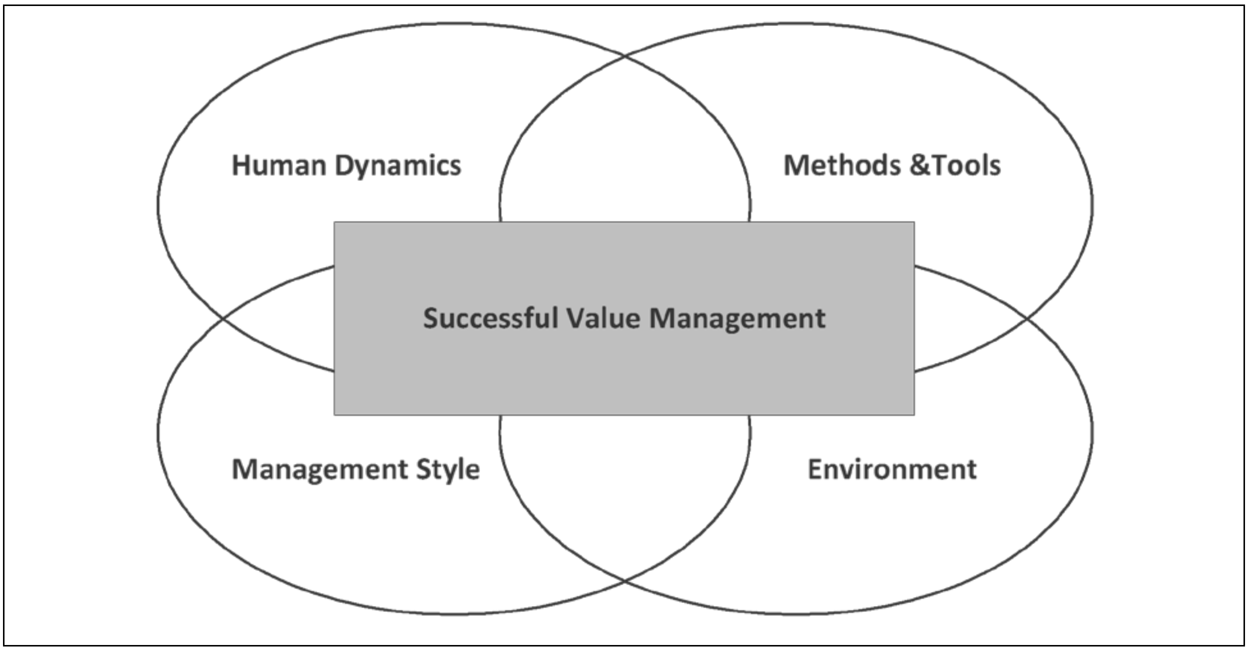

Fig. 3: Key Principles of Value Management[24]

2.6.1 Effective Use of Methods and Tools

The effective use of methods and tools contributes to the achievement of results. VM provides the framework, in which proven management methods can be applied in a structured and logical way. VM brings these methods together and ensures that none of the methods is used in isolation, rather in a holistic approach and aligned to the organization's policy. Using these methods, issues can be tackled effectively at each management level.[25]

2.6.2 Human Dynamics

The most precious resources of any organization are its employees. It is, therefore, very important to address employees' technical skills, management skills and ability to communicate properly, so that the employees perform their best. Collaboration between the employees is essential for the success of any project.[26]

[24] Cf. EN 12973 (2000), p.16 (own illustration)
[25] Cf. Pauwels (2001), pp.23-24
[26] Cf. VDI (2011), p.18

VM takes these interpersonal relationships into account by considering the following points:[27]

- *Teamwork*: Teamwork encourages the cooperation of people to achieve common solutions and reduce confrontations. Teamwork is enormously important for the achievement of effective results. Each member can make a different but useful contribution to the team. A well-chosen and well-trained team, which is communicating effectively, works with synergy, provides enhanced performance and is willing to accept responsibility for the developed result and its implementation.

- *Satisfaction:* The moderator and supervisors give recognition and credit for individual contributions and team results. The human being is seen as a whole and not only reduced to its work performance. This increases the motivation and satisfaction of employees and the quality of their work results.

- *Communication:* The basis of any collaboration between different people is communication. With the improvement of interpersonal communication, a better understanding is generally fostered amongst colleagues. The conclusion of group decisions is supported. A major advantage of VM is the improvement of communication between the employees of various company divisions. On the one hand, this results due to the general promotion of communication and on the other hand by the frequent teamwork.

- *Encouraging change:* The employees in a company should critically question their actions and challenge the "status quo" to bring about beneficial change. This increases the motivation to achieve continuous improvements.

- *Ownership:* It is important that the employees identify themselves with their task and thus accept responsibility for their actions. The persons, who are responsible for the implementation, assume the ownership of the results of VM activities.

2.6.3 Management Style

The VM style combines several essential properties in order to ensure the application of the concept of value and function. These include the promotion of teamwork and

[27] Cf. EN 12973 (2000), p.10; Cf. VDI (2011), pp.18-19

communication as well as the focus on what things do and how they work and less on what they are (functional approach). Furthermore, an atmosphere, which encourages creativity and innovation is created and emphasis is placed on the customers' requirements. Alternatives should be evaluated quantitatively in order to obtain a solid basis for the comparison of different options.[28]

2.6.4 Environmental Considerations

The environment, in which the entity, the organization or the project operates, must be considered for each individual management activity. The environmental factors determine the internal and external framework for the company. The external conditions, to which the managers have little or no influence, need to be taken into account. These conditions may represent both opportunities and constraints (requirements).[29]

The following areas are especially significant:[30]

- Organization
- Customers
- Suppliers
- Laws and administrative regulations
- Ecology

Further examples of external environmental factors are national and international practices, processing guidelines, social and economic behaviour, market conditions, physical barriers and infrastructure and limited availability of resources. It is also possible that conditions exist within an organization, over which managers have little influence.[31]

Examples of this are:[32]

- Internal politics and organizational rules
- Knowledge, experience and capabilities of the staff
- Corporate culture and human relations
- Existing organizational and business processes
- Financial limits

[28] Cf. EN 12973 (2000), p.10
[29] Cf. VDI (2011), p.19
[30] Ibidem
[31] Ibidem
[32] Ibidem

Finally, it can be noted that all four individual factors cannot be considered independently rather they influence each other. To ensure the continuous success of VA, all elements need to be taken into account and impacted in a positive way.

2.7 Success Factors of Value Analysis

The success of Value Analysis (VA) is mainly based on the following four characteristics:[33]

- Interdisciplinary teamwork
- The concept of value
- The concept of function
- Value Analysis work plan

The following sections provide a short introduction for each of these characteristics.

Interdisciplinary Teamwork

Usually, the organizational side of a company is divided into several departments. With their special knowledge and experience areas, such departments only address their specific issues out of the overall company issues. Moreover, because of the ever-growing knowledge in all fields, the increasing flood of information and constantly increasing complexity of equipment and processes, a further specialization by individuals, in subfields is required. This also means that each department tries to achieve the best possible cost-benefit ratio in their field. Therefore, the ultimate goal of the company, which is maximizing the total value of the company, often cannot be realized. Each department is looking through their "department glasses" and pursues their own departmental goals. If employees from different departments come together to solve arising problems, this leads to an overall project-related knowledge. This collaboration is the basis for coping with the task at hand efficiently and sustainably. The interdisciplinary teamwork within the VA can take place with customers, suppliers and service providers. The common focus on the overall goal is crucial and can be ensured by a neutral moderator of the interdisciplinary team. This also ensures that the results consider the expertise of all participants. Only in this way is it possible to achieve a quick and practical realization of the conceptual results. During VA project work, informal learning processes take place which stimulate the cross-functional communication within the company. The people assisting in the VA

[33] Cf. VDI (2011), p.3

projects are key figures for the necessary change process and they give their companies access to organizational resources, money, time and knowledge, as well as innovative growth.[34]

The Concept of Value

The term "value" is assigned with different meanings, in various disciplines, such as mathematics, economics, physics, or philosophy. Even within the VA, "value" has long been understood as only the ratio of benefit to cost. The costs were the determining factor. But this definition is not sufficient. What might be accurate enough in assessing the use value of an object (e.g. safety against failure of a relevant component), is no longer appropriate for evaluating the esteem value of objects. A piece of jewellery, for instance, is more valuable, the more expensive it is. Finally, it may also add to owner esteem, prestige, reputation and satisfy aesthetic needs. Therefore, by the "value of an object", VA understands how valuable, important and significant the object is for "someone", for example, an institution (authority, university, state, country), a company (manufacturers, users, employees) or a person (or group of people) as "target market."[35]

The Concept of Function

The basic idea of Functional Analysis (FA) is that the customer does not want to have the object itself but its functions, which means its effects. When developing a new object or revising an existing object, the project team has to describe these functions in an appropriate manner. For example, the buyer of a car beverage holder does not necessarily want to have one special commercial holder. Actually, what the driver wants is that; the liquid of an open beverage does not overflow while driving and that the can remains in place; that it can be reached easily; that there is no security risk from the can, etc. The customer only wants to use the functions of the holder, such as "fix beverage can", "prevent liquid loss", "consider ergonomics" and "maintain safety". By focusing on the functions it is possible to dissociate from the actual solution level. This level is always subjective and often "defended" by the person concerned. The functional level is objective and leaves room for new ideas: for solutions for the definition of the desired state. The direct path from an existing solution "X" to an optimized solution "X" is difficult because it is subjective. By

[34] Cf. Ehrlenspiel/Kiewert/Lindemann (2005), p.116; Cf. VDI (2011), pp.4-5
[35] Cf. Pauwels (2001), p.31

analysing the functions it is possible to dissociate from the current state and generate new ideas.[36]

Value Analysis Work Plan

The structure of the VA work plan follows the general sequence of human thoughts:[37]

- Identify what is
- Describe what should be
- Find ideas
- Evaluate and decide

For a VA project, the "project preparation" must be added at the beginning and the "implementation" at the end. Therefore, the European work plan (according to EN 12973) consists of ten basic steps, which follow the same scheme. Through this naturalness, it is very simple to work with the VA work plan. At the same time, the project team is forced to systematically work through the project, step by step.[38] This is because:[39]

- Only when the project contract is signed, does one wish to work on the project well and fights for its objectives.
- Only if one knows the task, the objectives and constraints of the project, is it possible to describe the actual state of the VA object.
- Only when one knows the exact conditions of the VA object basis, can the desired or required target state be defined.
- Only if one has defined the desired state, can the search for ideas begin.
- Only when one finds comprehensive ideas, can the best solution concept be created.
- Only when one has found the best solution, and this concept has been approved by the client, can the implementation phase begin.

[36] Cf. Ehrlenspiel/Kiewert/Lindemann (2005), p.117; Cf. VDI (2011), pp.5-6
[37] Cf. VDI (2011), p.7
[38] Ibidem
[39] Ibidem

2.8 Achievements of Value Analysis

Success with the method Value Analysis (VA) can be realized in various areas:[40]

- *Reduced costs:* The reduction of manufacturing costs is between 5 and 60 percent. The average reduction of manufacturing cost of several thousand Value analysis projects is 20 to 25 percent. Reasons for the relatively large margin are mainly:
  - The initial state of the VA object
  - The time of application of the VA (development process or mass production)
  - The degrees of freedom in the project
- *Short amortization period:* The amortization period is an indicator for the success of the VA project. For most projects, the amortization time is about one year, for a few it is significantly less. Usually, the amortization calculation covers team member meetings, necessary tasks between meetings, as well as investments for the changes in the VA object, such as new tools, trials or certifications.

- *Shortened development time:* The shortening of the development time is within the range of 25 percent and 50 percent. This aspect is becoming more important due to short product life cycles and rapidly changing markets. The effect of the shortening of development time is due to the fact that all concerned departments work together from the very beginning and exchange ideas. Thus, many iteration steps do not even arise. This also results in a solution that is accepted equally and encouraged by all departments.

- *Improved quality:* Due to the holistic approach and the integration of the relevant business departments, all aspects of product quality may be considered in the product development process.

- *Increased functionality:* Functional Analysis (FA) allows a detailed consideration of all functions required by the customer and the unnecessary functions. Therefore, the VA object can be adapted to all honoured customer requirements.

[40] Cf. VDI (2011), pp.8-10

- *Better communication within the company:* Thanks to interdisciplinary teamwork, the communication encourages between different departments. The positive experiences of a VA project are also felt outside of the project team, within the company and even after project completion.

2.9 The Concept of Value

This chapter explains the concept of value. In the following sections, definitions of the terms; value, need, function, resource and value comparison are given.

2.9.1 Value

The term “value” is defined *“[…] as the relationship between the satisfaction of needs and the resources used in achieving that satisfaction”* [41] (see Fig. 4).

Fig. 4: The Concept of Value[42]

The better needs are satisfied and/or the less resources are used, the higher the value. But value is not an absolute measure and may be viewed differently by different parties, in differing situations. It is seen more as a balancing of conflicting parameters that vary from organization to organization, depending on the company’s objectives. (Therefore the symbol α is used.) For the customers, for example, the value is the extent to which the offer fulfils their expectations, in relation to the amount the consumers have to spend to acquire and use a product or service. For the supplier, the fewer resources needed to satisfy the external customer, the higher the value.[43]

In order to provide evidence, the value improvement must be made measurable. Therefore, the needs are represented by functions of objects and the resources by cost, material, human resources and time. The optimization of value is achieved by balancing the amount to which needs are satisfied against the resources utilized. It is

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[41] EN 12973 (2000), p.12
[42] Ibidem
[43] Cf. EN 12973 (2000), p.12

important to recognise that a value improvement may also arise from an increase in the satisfaction of needs, while also increasing the resources required. This is provided that the satisfaction of needs increases more than the use of resources (see Fig. 5).[44]

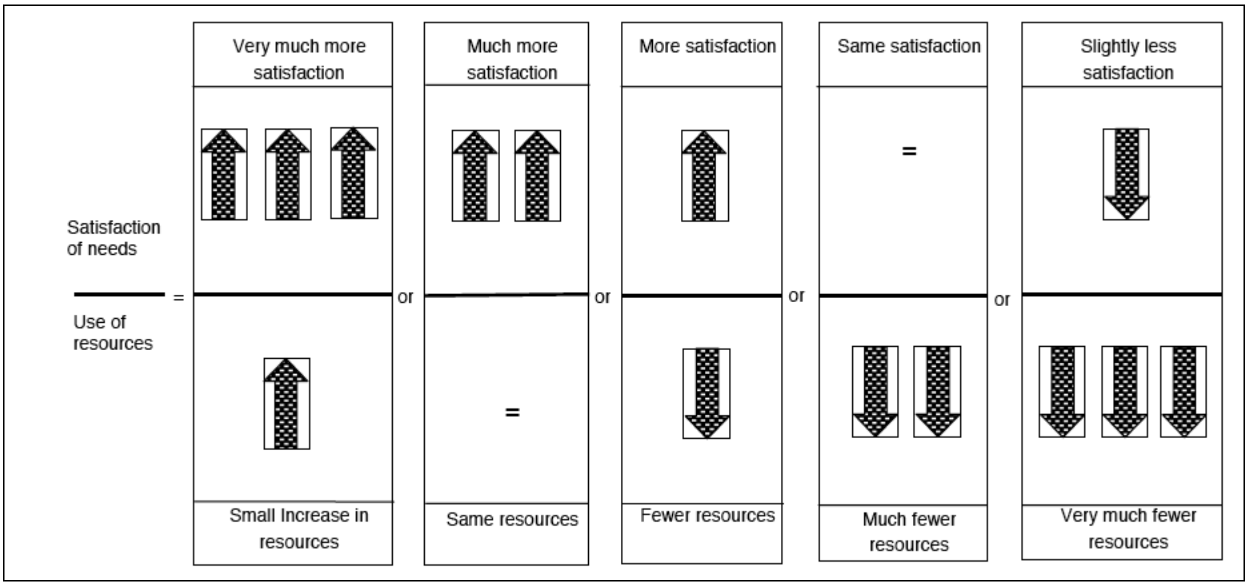

Fig. 5: Different Ways of Achieving Equal Value Increases[45]

2.9.2 Need

Need is defined *"[…] as what is necessary for or desired by the user."* [46] Depending on specific situations, the needs of the management are different. The total need generally comprises many different components. [47]

For example, the following two needs are distinguished:[48]

- *Use needs:* These needs are components of the total need, which relate to tangible and measurable activities. E.g. from a manager's point of view, the factory should produce output. From the production manager's point of view, the purchasing department should have processes that allow the organization to purchase raw materials and other items at the best prices.

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[44] Cf. EN 12973 (2000), pp.12-13
[45] EN 12973 (2000), p.13
[46] Ibidem
[47] Cf. Pauwels (2001), p.31
[48] Ibidem

- *Esteem Needs:* These needs are components of the total need, which are subjective, attractive and moral. A factory may also impress customers and generate revenue. The purchasing department should have properties that encourage people to do business with them and maintain staff loyalty.

It is easy to measure the degree to which some needs are satisfied. This is quite difficult for other needs. If the satisfaction of a need cannot be quantified in monetary units, the project team needs to assess it. Here, various evaluation methods can be used. A need may arise, subsist, develop or disappear due to various reasons e.g. changes in the available technology. However, every need has to be satisfied by the performed functions of the product or service.[49]

2.9.3 Functions

The definition of a function is the effect of a product or its constituent parts. A need can be described objectively by certain functional requirements. With the help of evaluation criteria, it is possible to assess functional performance. Usually, functions are described by using an active verb and a measurable noun. For a good measure of value the functions fulfilled by the product should match the required functions for the satisfaction of the need exactly. The abstracting representation of functions is necessary in order to foster creativity and thus create a larger clearance for the exploration of innovative solutions. The concept of function is described in more detail in chapter 2.10.[50]

2.9.4 Resources

Resources comprise whatever it takes to satisfy a need. Resources include money, time, and physical commodities, such as materials or intangible variables, such as intellectual property. Basically, the availability of resources is limited, which may be of greater importance than their monetary cost. In general, all resources can be related to expenses. When developing new products or services, all resources required must be estimated. For existing products and services, the current consumption of resources can be determined as a basis for the measurement of improvements.

[49] Cf. EN 12973 (2000), p.14
[50] Cf. Pauwels (2001), p.161-162

Recently, the importance of the factor, ‘time’ has increased because simply being the first in the market place, may already be advantageous.[51]

2.9.5 Value Comparison

Once the satisfaction of needs and the use of resources are quantified, their ratio is a measure of value, which can be used to compare solutions with each other (see Fig. 6).[52]

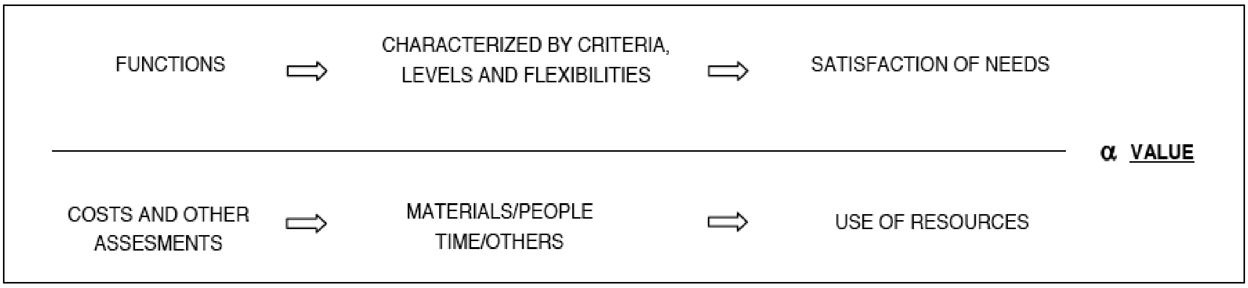

Fig. 6: The Relationship between Needs, Functions and Criteria, and Resources[53]

2.10 The Concept of Function

As already mentioned in section 2.9.3, a function describes the effect of a product or its constituent parts and no solutions.[54] Thereby, “effect”, means both the effect as a process and also the result of an activity.[55] Performance indicators accompany a function.[56] According to AKIYAMA, the word “function” has three interpretations. Firstly, functions are effects or activities of tangible and intangible “things”. Secondly, functions are functional, which means that the Functional Analysis (FA) deals with functions of products, processes and services and not with functions of natural phenomena. This leads to the third acceptation that functions are concepts.[57] Nevertheless, functions are the "core elements" of VA.[58]

The naming of functions is done with a verb and a substantive. The verb indicates the type of activity that is required for the satisfaction of a need and the noun describes the element on which the activity is performed. The wording must be short and precise, common and easy to understand, without ambiguity and having no

[51] Cf. EN 12973 (2000), p.15
[52] Ibidem
[53] EN 12973 (2000), p.15
[54] Cf. EN 12973 (2000), p.14; Cf. VDI (2011), p.58
[55] Cf. http://imihome.imi.uni-karlsruhe.de, date of access: 28.11.2012
[56] Cf. EN 12973 (2000), p.38
[57] Cf. Akiyama (1994), p.25
[58] Cf. Kaniowsky (1992), p.220

direct relation to the observed object.[59] Generally, the verb should be an active verb, e.g. “turn the valve”, “press the button”, and “show values”.[60] Table 2 shows a few examples for the preferred way to name functions in comparison to the least preferred method of naming functions.

Preferred Method of Naming Functions	**Least Preferred Method of Naming Functions**
Generate heat	Produce flame
Connect parts	Screw sheets
Turn valve	Allow valve rotation
Transfer liquid	Allow liquid transfer

Table 2: Naming of Functions[61]

Nor is it important to work out the right level of abstraction in the naming of functions. Choosing the right level of abstraction is a difficult task, especially for inexperienced people. The functions of the target state should open a large search area for new solutions in the subsequent creative phase of the VA. For this reason, the naming of functions needs to be sufficiently abstract. This means that the functions are possibly not simply a reflection of the reality of the actual situation. Then, the search for solutions may only refer to a “solution road” and not to a “solution field”.[62]

The level of abstraction can be divided into three main areas:[63]

- *Real,* i.e. no abstraction
- *Iconic,* i.e. visual-graphic description
- *Symbolic,* i.e. verbal-abstract description

The optimal abstraction level for the naming of functions lies on the border between iconic and symbolic description, where functions can no longer be represented in their full significance. The naming of functions thus moves from the iconic towards the symbolic area. The subsequent production of ideas takes place in the opposite direction - back from the symbolic to the iconic area.[64]

[59] Cf. Akiyama (1994), p.58; Cf. EN 12973 (2000), p.40
[60] Cf. VDI (2011), p.58
[61] Cf. VDI (2011), pp.58-59 (own illustration)
[62] Cf. Pauwels (2001), p.166
[63] Cf. Pauwels (2001), p.167
[64] Cf. Pauwels (2001), pp.167-168

Additionally, functions should be quantifiable. These quantitatively rated values ensure that the market demands are met exactly. The effect defining parameters also provide the basis for the evaluation of the degree of functional performance. [65]

Functions can be divided according to four criteria: into function types, function classes, target and actual functions, and undesirable. The classifications of functions are summarized in Fig. 7.

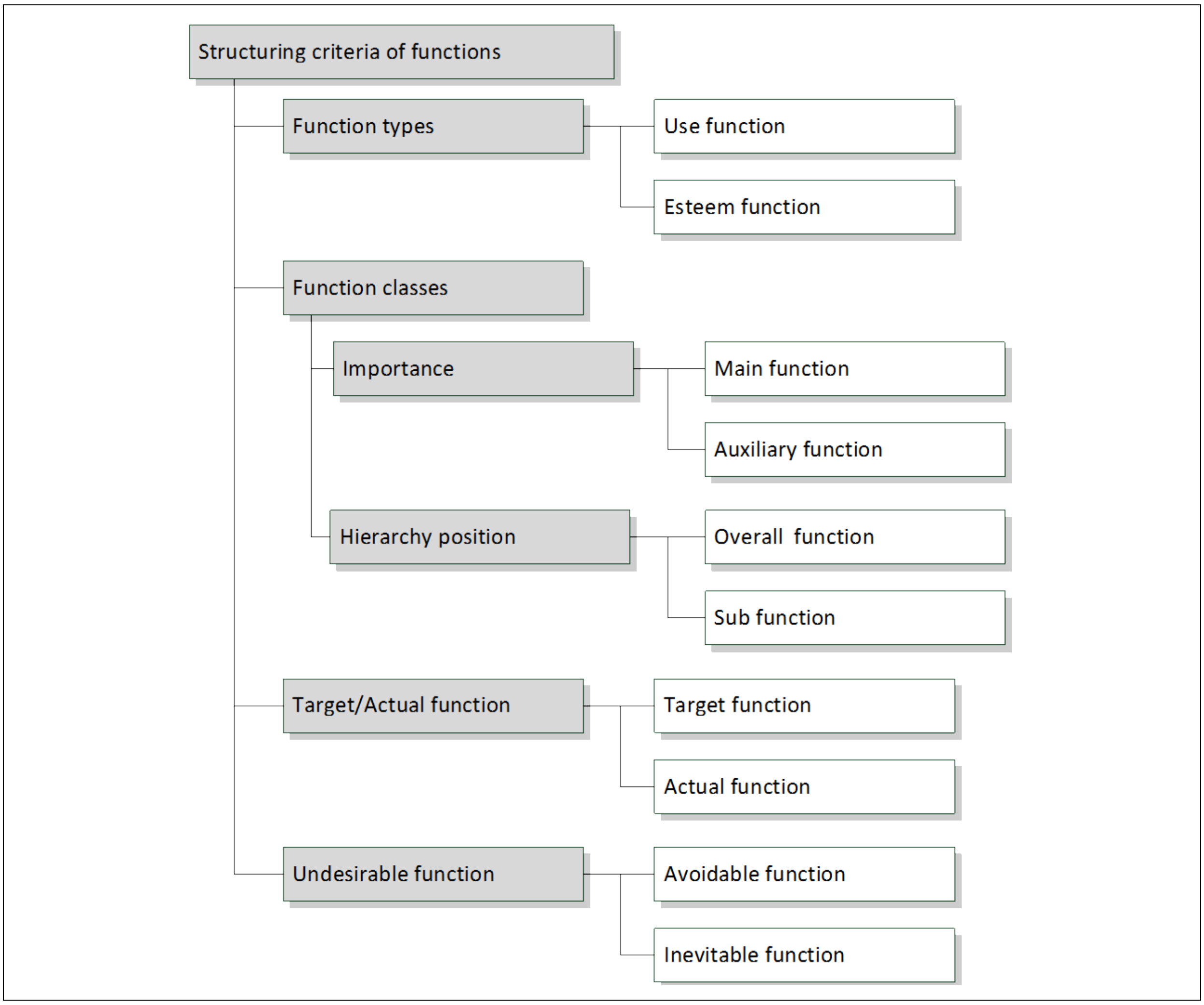

Fig. 7: Structuring Criteria of Functions[66]

[65] Cf. VDI (2011), p.59
[66] Cf. VDI-Richtlinie 2800 (2000), pp.4-5 (own illustration)

Function Types

With regards to the FA, two types of functions can be distinguished:[67]

- *Use functions:* These functions are required for the technical and economic usage of the VA object and are usually quantifiable. E.g. “conduct electricity”, “separate mixtures” or “store energy”.

- *Esteem functions:* These functions only fulfill aesthetic or prestige-oriented demands and are usually only subjectively quantifiable. Esteem functions do not affect the use functions. E.g. “robe bearer”, “create impression” or “provide status”.

Investment goods usually outweigh the use functions, while for consumer goods especially luxury goods, esteem functions encourage the purchase of a product. However, in a VA study, both function types need to be taken into account because many purchasing decisions are made due to taste aspects or prestige reasons (see Fig. 8).[68]

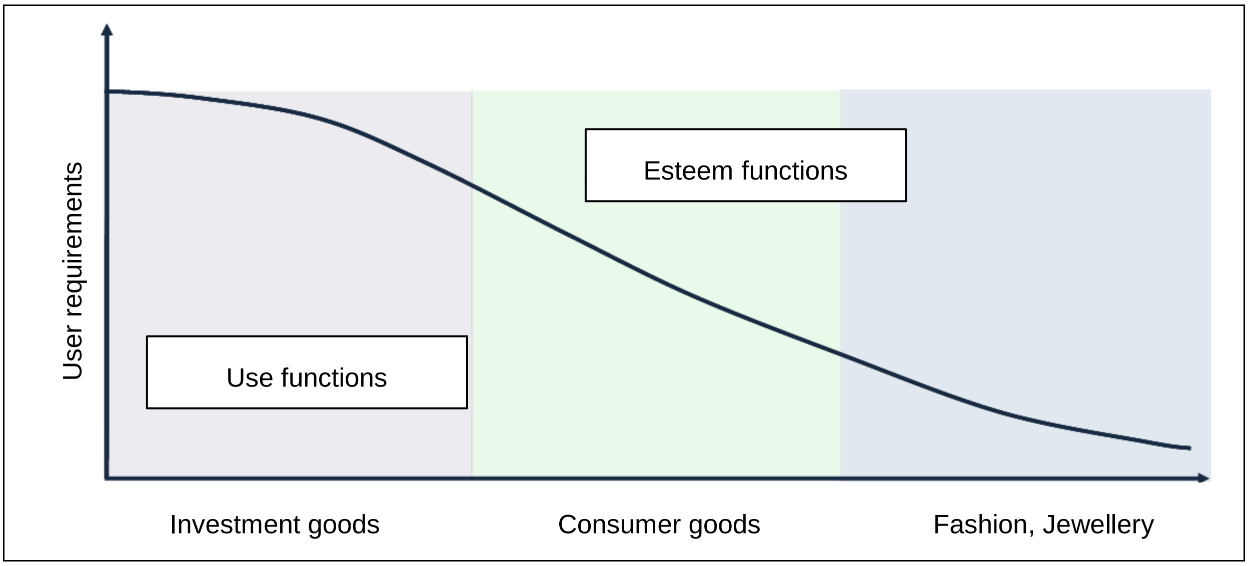

Fig. 8: User Requirements on Different Objects[69]

[67] Cf. VDI (2011), p.60
[68] Ibidem
[69] Ibidem

Function Classes

The classification into function classes depends, on the one hand on the importance of the functions and on the other hand on their hierarchical position in the functional structure:[70]

- *Main functions:* Main functions describe the purpose of an object - their fulfillment is essential.
- *Auxiliary functions:* These functions describe other necessary tasks and support the main functions. Auxiliary functions are usually determined by the solution concept.
- *Overall function:* The overall function is the overall effect of all the subordinated functions in the functional structure of an object.
- *Sub function:* Sub functions are those functions of a functional structure, which come about due to their interaction in the overall function.

Target/Actual Functions

With regards to the development latitude and the limitations of the search field for functions, it is possible to divide the functions into ‘target’ and ‘actual functions’:[71]

- *Target functions:* Target functions can be derived from the objective of the VA work. These functions are the basis for searching for solutions and for all subsequent work steps in the VA work plan. Target functions describe the target state that should be achieved. Target functions can also be actual functions at the same time.
- *Actual functions:* Actual functions are the functions, which are identified at the beginning of a VA study on object or in the requirements specification sheet. Actual functions are derived directly from the actual situation.

[70] Cf. Ponn/Lindemann (2008), pp.58-60
[71] Cf. Bronner (2006), pp.16-17

Undesirable Functions

Undesirable functions are functions that have a negative effect for the user. These functions are directly related to the actual functions because they are determined to be undesirable during the analysis of the VA object.[72]

Undesirable functions can be either avoidable or inevitable:[73]

- *Avoidable functions:* Avoidable functions (unnecessary functions) may only occur in the analysis of the actual state but not in the formulation of the target state. They make no contribution to the satisfaction of user needs and therefore, no positive contribution to the value of a product.
- *Inevitable functions:* Inevitable functions may occur in the analysis of the actual state as well as in the formulation of the target state.

User-related/Product-related Function

EN 12973 divides functions into user-related functions and product-related functions:[74]

- *User-related functions:* These functions describe what objects do to meet the needs of users throughout the entire product lifecycle. The question is: "What for?"
- *Product-related functions*: These functions describe the product's internal mechanisms for realizing solutions for the needs. The question is: "How?“

2.11 Value Analysis Work Plan

An essential attribute of Value Analysis (VA) is its work plan with primary and sub-steps, which describe the structure of the work. Thus, the participants gain guidance for their actions. There are various VA work plans, which cannot be distinguished in their content structure but rather in the detailing of the work packages. This is reflected by the different number of primary and sub-steps.

[72] Cf. Pauwels (2001) p.173
[73] Ibidem
[74] Cf. EN 12973 (2000), p.39

The following approaches can be identified in German-speaking countries:

- The most recently developed work plan is the work plan according to EN 12973. It consists of one preparation step and nine basic steps.[75]
- The work plan according to VDI-Directive 2800 originates from the no longer valid norm DIN 69910 and comprises six basic steps.[76]
- The work plan according to ÖNORM A 6760 also consists of six basic steps and equates to the no longer valid norm ÖNORM A 6757.[77]

In the application of all these proceeding diagrams, it is crucial to consider two guidelines. Firstly, the basic steps of the sequence must be followed in any application. The design of the sub-steps can be project-specific. Secondly, to ensure the project's progress, the subsequent basic step should only start when the previous one is completed. If an approximation to the objective is not recognizable or when it is expedient, work steps can be repeated several times iteratively.[78] However, the VA task, the VA environment and the project team's performance determine the actual work plan.[79]

For further work, the VA work plan according to EN 12973 is taken as a basis. This work plan, with its ten steps, may not be as clear as the other two mentioned but this one is the most recently developed and thus the most actual one.

Fig. 9 shows the ten-step work plan according to EN 12973. The following chapters describe each individual step of the work plan. Detailed explanations of the work tasks provide an overview of the linear procedure to which the method VA is strictly bound.

[75] Cf. EN 12973 (2000), p.31
[76] Cf. VDI (2000), p.13
[77] Cf. ÖNORM A 6760 (2002), p.15
[78] Cf. VDI-Richtlinie 2800 (2000), pp.8-9
[79] Cf. Kaniowsky (1992), p.107

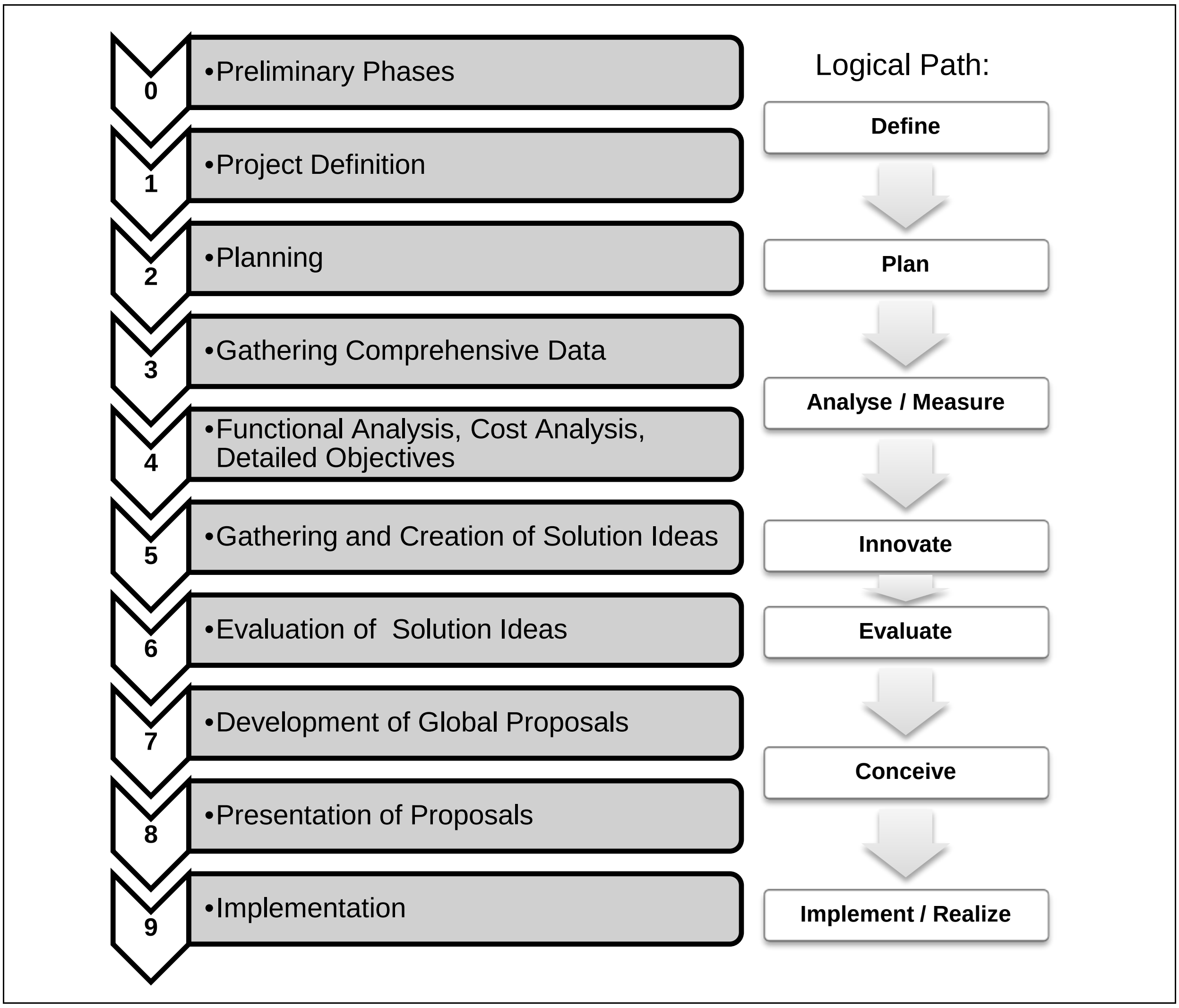

Fig. 9: Value Analysis Work Plan[80]

Table 3 displays the division of responsibility and participation in each step of the VA work plan. Here, it can be seen which work steps the decision maker, the project leader and the working group are involved in. But responsibility and participation vary from project to project and from organization to organization.

[80] Cf. VDI (2011), p.40 (own illustration)

Responsibility (●) and participation (X) during the phases of the VA work plan					
Phase Name	Phase Nr.	Decision maker	Team leader or VA project leader	Working group	Operational departments
Preliminary Phase	0	●			X
Project Definition	1	●	X		X
Planning	2		●		
Gathering data	3		●	X	X
Functional Analysis	4		●	●	X
Gathering Ideas	5		●	●	X
Evaluation of solutions	6		X	X	●
Development of proposals	7		●	●	X
Presentation of proposals	8	●	●	●	X
Implementation	9	●	X		●

Table 3: Responsibility and Participation during the Phases of the Value Analysis Work Plan[81]

2.11.1 Work Step 0 "Preliminary Phases"

In this work step, primarily the client is asked to clarify critical requirements for a VA project.[82] This basically includes the project outline and feasibility, profitability and risk investigations.[83]

The following two questions may be helpful in encircling project tasks or VA objects:[84]

- Where and why is the competition ahead?
- Where is innovation, change, renewal, repair needed?

The selection of a VA object must be carried out in accordance with the organization's policy.[85]

The project manager and the VA moderator also need to be selected. If appropriate, both responsibilities - organizational manager and methodical coach - are transferred

[81] EN 12973 (2000), p.38
[82] Cf. VDI (2011), p.41
[83] Cf. EN 12973 (2000), p.32
[84] Cf. VDI (2011), p.42
[85] Cf. VDI (2011), pp.41-42

to one person. It is important that this function conducts someone who has sufficient technical, methodical and social competence for the system VA.[86]

Methodical tools, which can be used in a meaningful way in this step of the work plan, are e.g. portfolio models, ABC analysis, SWOT analysis, Scenario Technique, Quality Function Deployment (QFD) and Target Costing.[87]

2.11.2 Work Step 1 “Project Definition”

After selecting the VA object, it is necessary to define the general framework of the study because laws, regulations, operating conditions and other criteria limit the solution field.[88] According to that framework, quantified and global objectives, like cost goals, quality, market expectations, time and environmental and human targets need to be defined. In many cases, a requirements specification sheet including all possible influencing factors (market needs, competition, information and material flow, hard- and software, etc.) specifies the project definition.[89]

Possible objective directions are:[90]

- Cost reduction
- Functional improvements
- Quality improvements
- Complaints reduction
- Capacity increase
- Productivity increase
- Design improvement
- New applications

Some methodical tools, which can be used for defining objectives for a project, are QFD, Failure Mode and Effects Analysis (FMEA), Goal Setting, Market analysis, and Benchmarking.[91]

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[86] Cf. VDI (2011), p.41
[87] Ibidem
[88] Cf. Bronner (2006), p.25
[89] Cf. Pauwels (2001), pp.48-49
[90] Cf. VDI (2011), p.44
[91] Cf. VDI (2011), pp.43-44

2.11.3 Work Step 2 "Planning"

Only when tasks and goals of the VA project are clearly defined, may the project leader form the project team. Due to the fact that value analytical tasks are quite complex, it is essential to integrate experts from different departments into the so-called cross-functional team. Depending on the complexity of the project topic, the project team consists of a maximum of eight and a minimum of four people. In accordance with the client, the project moderator plans the VA project's time schedule.[92]

In the project kick-off meeting, the following agenda items are discussed:[93]

1. Presentation of the project topic and objectives; clarifying open questions
2. Presentation of time and capacity plan
3. Thematic and organizational planning of the project team meetings
4. Collection of work packages for preparing the first project team meeting

Methodical tools, which are useful within work step 2 are, for example, team-building and Project Management.[94]

2.11.4 Work Step 3 "Gathering Comprehensive Data"

At this point, the project teamwork begins with collecting and analysing relevant data concerning the VA project. Information about the weaknesses of the product concerned and the strengths of competitors are represented and assessed. All directly influencing costs are collected and sorted. These are manufacturing costs, logistic costs, communication costs, development costs, material flow costs, etc. Also, intangible values, like quality defects, long distances, long process and throughput times, information and communication issues, need to be considered.[95]

The following methodical tools are helpful in work step 3:[96]

- Pareto Analysis
- ISHIKAWA-Diagram
- Simultaneous Engineering

[92] Cf. Pauwels (2001), p.52
[93] Cf. VDI (2011), pp.44-45
[94] Cf. VDI (2011), p.45
[95] Cf. Pauwels (2001), p.55-56
[96] Cf. VDI (2011), p.46

2.11.5 Work Step 4 "Functional Analysis, Cost Analysis, Detailed Objectives"

The first part of this chapter specifies the Functional Analysis (FA) method. Subsequently, the general practice of the Function Cost Analysis is explained. The last section describes how it is possible to derive detailed goals from ascertained results.

Functional Analysis

According to EN 12973, the FA is used to detect functions of products, systems or organizations. Furthermore, the validation, characterization and structuring of functions is part of this method.[97] AKIYAMA describes the meaning of FA as the analysis of objects for their effects, purposes and concepts.[98]

The FA is a process in the VA, with the objective of obtaining a complete description of the functions and their relationships, which can be systematically represented, classified and assessed. The result is the illustration of the function model within a chart (e.g. function tree).[99]

Focal points in performing the FA are: [100]

- The analytical representation of functions
- The classification of functions according to their effect
- The analysis of the interaction function - function carrier
- The weighting in terms of cost and functions
- The representation of the effect of a function and assigning the defining parameters
- Developing new approaches for solving identified problems

The following tasks are attributed to the FA:[101]

- The enabling of a "soft model formation" by verbal function phrasing, with optimized level of abstraction and function structures
- Creation of a larger search area for new, better and more cost-effective solutions by abstracting from the observed VA object

[97] Cf. EN 12973 (2000), p.39
[98] Cf. Akiyama (1994), p.26
[99] Cf. EN 12973 (2000), p.39
[100] Cf. Kaniowsky (1992), p.135
[101] Cf. http://imihome.imi.uni-karlsruhe.de, date of access: 28.11.2012

- Initiation of a learning process for the precise detection of a deficient current status, compared to the desired target state of the VA object
- Identification of simplifications and improvements by distinguishing between important and less important, or even unnecessary functions
- Determination of cost focuses and detection of targets for cost reductions and performance improvements through determination of the function costs

Additionally, the FA is used to quantify the achievable degree of functional performance. It is important to remember that the method acts as a means of improved communication between people who are involved in the definition, design and development process of the VA object.[102]

The FA requires the team members to free themselves from solutions and to think in terms of goals and results. This abstract contemplation lifts restrictions and stimulates creativity.[103]

Advantages of FA:[104]

- Systematic approach
- Method for finding completely new ideas

Disadvantages of FA:[105]

- Complex
- Time-consuming

Functional Analysis Process

In literature, there are different approaches to the FA procedure. This chapter briefly describes the FA process according to EN 12973. The three basic steps of the FA from AKIYAMA, the seven-step work plan according to VDI and the four functional modules of KANIOWSKY are presented as a comparison.

EN 12973 divides the FA process into five steps:[106]

1. *Identify and list functions:* The desired goal is a complete description of the object. As outlined above, an active verb and a noun depict every function.

[102] Cf. EN 12973 (2000), p.39
[103] Ibidem
[104] Cf. http://imihome.imi.uni-karlsruhe.de, date of access: 28.11.2012
[105] Ibidem
[106] Cf. EN 12973 (2000), pp.40-41

2. *Systematise functions:* At this point, the functions are arranged in a logical structure, for example in a function tree. All functions together must represent a complete qualitative description of the observed need.

3. *Characterization of functions:* This phase quantifies the different functions with their expected performance.

4. *Setting up a functional hierarchical order:* When setting up a hierarchical order, the functions are ranked according to their importance, which generally reflects the user's view.

5. *Evaluation of functions:* The functions are assigned with a "weight" that represents a quantification of the hierarchy. The arrangement of functions in a hierarchical structure and the evaluation are necessary to specify the expectations of the users, which should be considered during the product design process.

In contrast, the approach of FA by AKIYAMA consists of three basic steps, which are illustrated in Fig. 10:[107]

- *Capturing of the analysis object:* An important basis for a successful FA is the correct and error free capturing of the analysis object. This includes accurate data collection and preparation. At this stage, a common view and way of speaking about the object among all persons involved in the FA project is also important.

- *Naming of functions:* The "core" of the FA is the naming of functions. Therefore, AKIYAMA also uses a verbal model with a verb-noun pair.

- *Structuring of functions:* The structuring of functions has an important role in the FA. The various functions do not take an isolated position within the system but they remain in a certain interactive relation to each other. These relationships can be graphically represented; in a function tree, for instance.

[107] Cf. Akiyama (1994), p.30

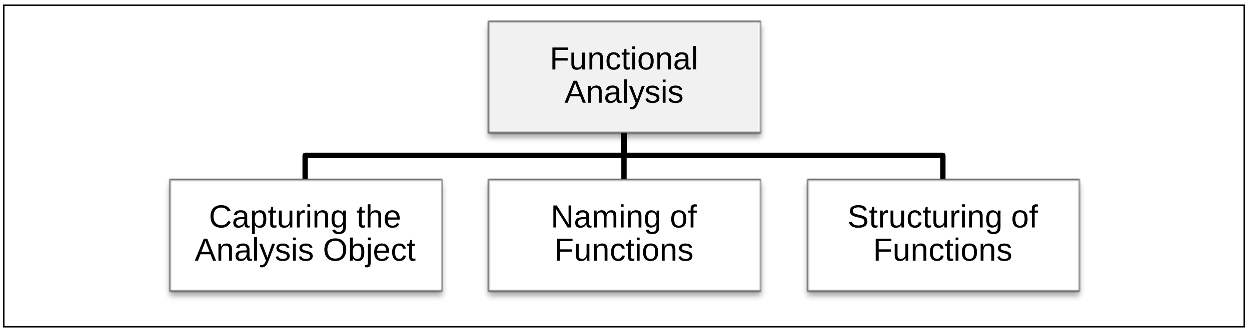

Fig. 10: The Approach of Functional Analysis by AKIYAMA[108]

The work plan of the FA according to the Association of German Engineers (VDI) consists of the following seven steps:[109]

1. *Recognizing the tasks of the VA object:* In product and process development projects, the question is: "What should it do?" In improvement projects, the question is: "What does it do?"
2. *Describing the tasks of the object with functions*
3. *Classifying functions:* All functions are classified into ‘main functions’ and ‘auxiliary functions’.
4. *Structuring of functions:* This is done with the questions “Why?” and “How?”
5. *Determining the function efforts:* Here, it is important to take all modifiable factors into account.
6. *Determining the target functions:* This is done with the question: “Is the considered function necessary?" or "What should it do?"
7. *Defining the effort of the target functions*

The difference between the current and target effort is the existing potential for change of function. The larger the absolute difference in the comparison of the functions, the higher the priority during the further steps within the project framework. Thus, with the help of creativity techniques, it is possible to identify useful approaches for the search for new solutions.[110]

[108] Cf. Akiyama (1994), p.28 (own illustration)
[109] Cf. VDI (2011), p.66
[110] Cf. VDI (2011), p.67

KANIOWSKY reviewed the usual procedure of FA because the functions work is perceived to be difficult. This resulted in the requirement of systematization and structuring the work process of FA in a better way. KANIOWSKY therefore established four functional modules. With their help it is possible to develop abstracting formulations, based on specific information about the effects of objects. These formulations are required for the creative work with functions.[111]

The four function modules are:[112]

- *Function module 1 - Function carriers analysis:* Determining parts, processes and function carriers, which represent the actual situation or the desired solution. According to the respective VA task and VA goal, it is necessary to create a structure that makes the relationships between the various functions visible.

- *Function module 2 - Function carriers requirements:* Assigning all demands to the function carriers. The requirements can be taken from specification sheets, customer requests or legal regulations. The degree of fulfillment of the requirements must be determined.

- *Function module 3 - Analyse functions:* Formulation of functions of function carriers (abstract formulation of the effect). This should always be done with a verb (describes the function) and a noun (describes the function carrier).

- *Function module 4 - Function determining variables:* Assigning functions with function-determining variables. Such variables can be identified from the demands on the function carriers (see function module 2). The values are illustrated in a way, which provides information about the degree to which a function is fulfilled (degree of functional performance). The degree of functional performance refers to a particular solution and is an indication of potential for change. The determination of the degree of fulfillment is always done by comparing solutions to each other (e.g. actual / target). An absolute or relative number presents the degree of functional performance.

[111] Cf. Kaniowsky (1992), pp.135-136
[112] Cf. Kaniowsky (1992), pp.136-137

Function Tree

The interrelation of main and auxiliary functions can be represented graphically. The identified functions are grouped by rank and dependency. The aim of the graphical representation is to visualize the functional structure of the VA object and to identify dependency and crosslinks (see Fig. 11).[113]

The following two questions may help to order the functions:[114]

- *How* is the considered function fulfilled?
- *Why* is the considered function fulfilled?

An answer to the question "how" gives a subordinate function. An answer to the question "why" gives a superordinate function.[115]

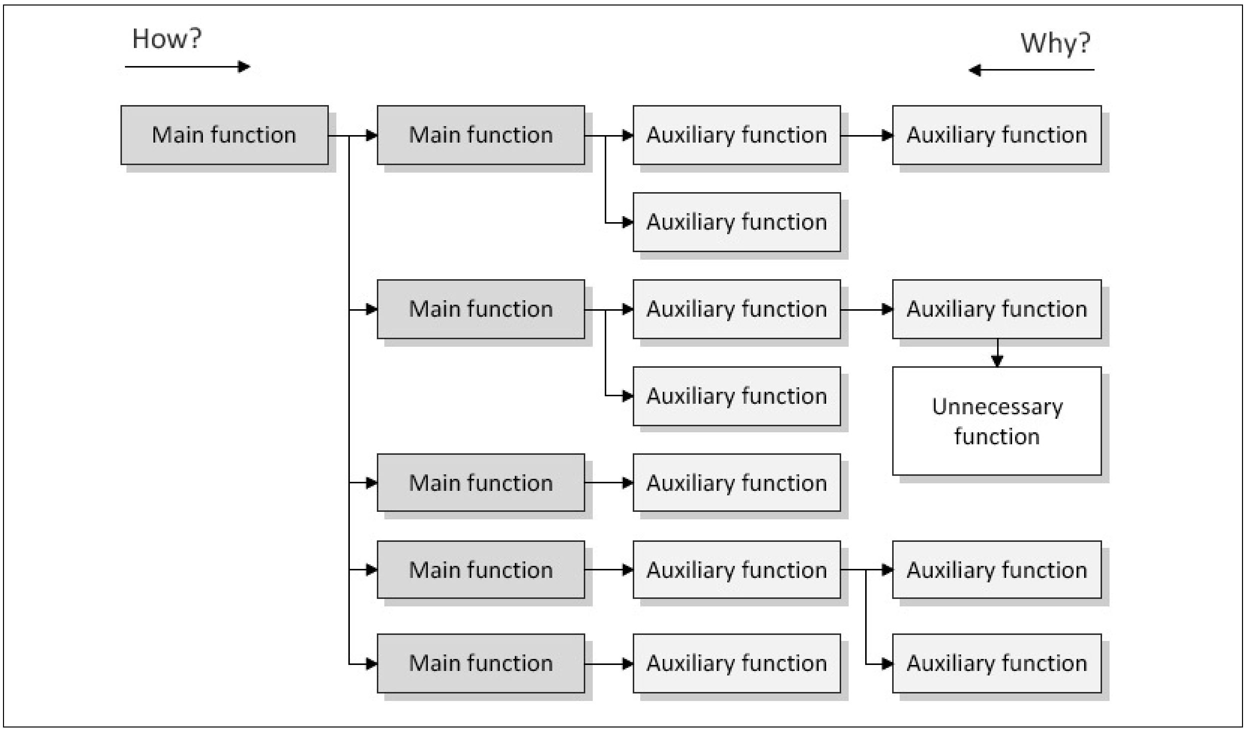

Fig. 11: Function Tree[116]

Another way for structuring functions is the Function Analysis System Technique (FAST).[117] In this thesis, FAST is not described in more detail.

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[113] Cf. Pauwels (2001), pp.174
[114] Cf. VDI (2011), p.63
[115] Ibidem
[116] Ibidem
[117] Cf. Akiyama (1994), p.32

Function Cost

Usually, the costs for an object are expressed by data of conventional part calculations. The allocation of costs to the functions of a product leads to new insights into how a product is considered. The determination of the function costs is part of the FA process.[118]

The cost of a function is the sum of the individual expenditures (use of resources) that are needed to provide the respective function in a product. The total costs of the object result from the sum of the costs of all different functions.[119]

The function costs consider only the initial costs, although the costs of the entire product life cycle must be taken into account. But the life cycle costs are hardly significant for isolated functions and therefore are usually not considered.[120]

The function costs are targets or estimations before the design or development process of a product is completed. Following the development, the function costs are those costs, which are actually incurred. Function costs may be inaccurate or unquestionable. If function costs are targets or limits, they are based on marketing considerations and technical feasibility. If function costs are examined for an existing product, data and estimates of the manufacturing planning can be used. These values are, however, only available for parts and assemblies and not for functions.[121]

Two methods are generally used for calculation or evaluation of function costs:[122]

- If it is possible to start with a given solution and to add or delete specific functions, the cost difference is an estimation of that function cost.
- If the cost of parts or assemblies can be roughly distributed to their performed functions, it is possible to get a cost estimation of each function, by adding the cost contribution of each part or assembly. Table 4 shows a function cost matrix, which is used for this calculation. Only an experienced work group can handle such a task.

[118] Cf. EN 12973 (2000), p.47
[119] Cf. Pauwels (2001), p.65
[120] Cf. EN 12973 (2000), p.48
[121] Ibidem
[122] Ibidem

Functions / Components	F 1		F 2		F 3		Costs of components	
	$	%	$	%	$	%	$	%
Component 1	a				b		a + b	
Component 2			c		d		c + d	
Component 3	e		f				e + f	
Costs of functions	a + e		c + f		b + d		a + b + c + d + e + f	

Table 4: Function Cost Matrix[123]

The preparation of the function cost analysis is carried out in three steps:[124]

1. Selection of functions to be evaluated
2. Linkage of components to the functions in percentage
3. Calculation of cost portions of the functions relating to the overall costs

In the first step, the functions that are important for the studied object are selected. The selection may be different on a case by case basis, depending on which level of detail is appropriate for a function, for the cost analysis. If a function is not important from a cost perspective, it can remain neglected. The calculation scheme guarantees that all costs are allocated to the selected functions.[125]

For the decision on whether to include a function or to select a different detail level, the following questions may be helpful:[126]

- Is the cost allocation less significant when choosing a rougher detail level?
- Is the function for the overall effect of the object important enough?
- Is the function in relation to the total cost of the object expensive enough?

In the second step of the function cost analysis, the selected functions are assigned with percentage proportions of the functional carriers. In this case, it is helpful to follow the question of to what extent the considered component is involved in the fulfillment of the respective function and in which proportion (see Fig. 12). This allocation is the basis for the calculation of cost portions, thus the second step in determining the proportions in percentage is really the decisive one. The discussion

[123] EN 12973 (2000), p.48
[124] Cf. Pauwels (2001), p.66
[125] Cf. VDI (2011), p.70
[126] Ibidem

on the allocation of proportions between team members is often connected with a learning process.[127]

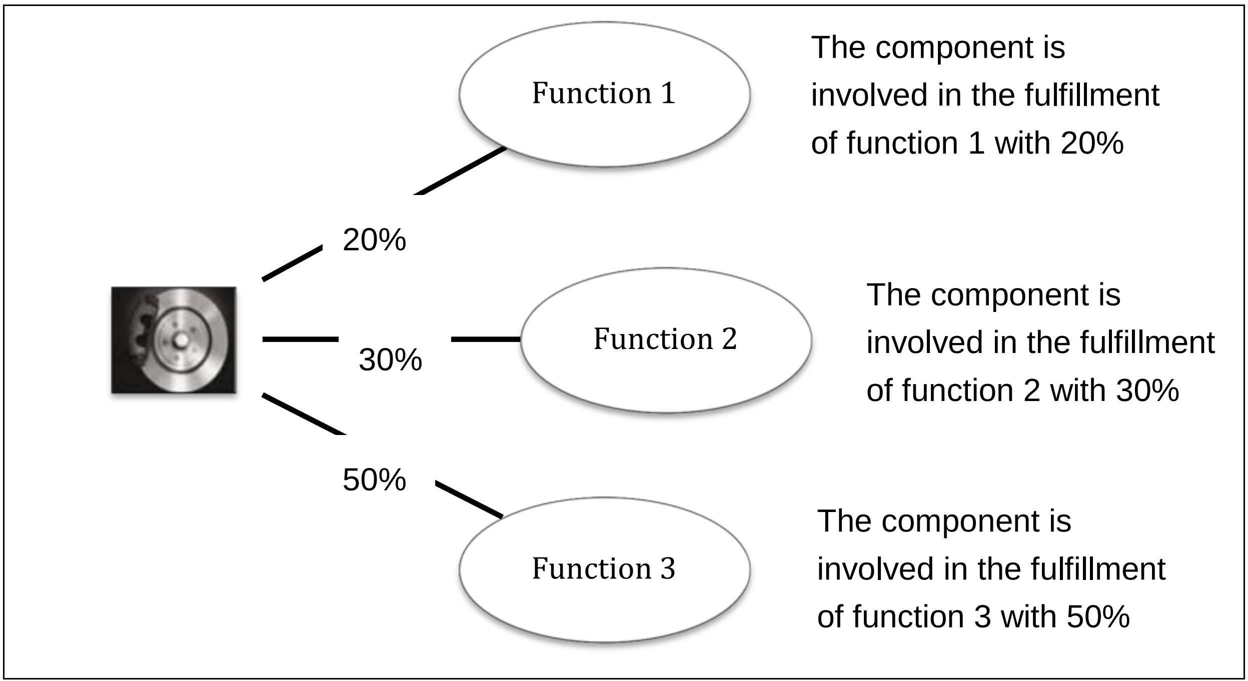

Fig. 12: Linkage of Components with Functions in Percentage[128]

In the third step, the cost portions of each function are calculated. Therefore, the total cost of the respective component is multiplied with the percentage proportion of the function defined in step 2. By adding up the various cost portions, the total cost for each function is calculated. The overall sum of all function costs has to match the total cost of the object. The complete process can be run through in the form of a table, as is displayed in Table 4. The individual cost portions provide an image of the cost distribution of the object, related to the effort required for the realization of its functions.[129]

Degree of Functional Performance

The object under investigation is subjected to a critical examination. The actual functions of existing objects are assessed according to their performance, with respect to the requirements. The examination of newly designed objects is made on the basis of the requirements specification sheet. An essential element of this step is

[127] Cf. VDI (2011), pp.70-71
[128] Cf. VDI (2011), p.71
[129] Ibidem

the assessment of the degree of functional performance. So the work group evaluates whether a specific function is fulfilled by the actual condition.[130]

Here, the goal is to identify the following functions:[131]

- Over-fulfilled function (degree of functional performance greater than 100 percent)
- Under-fulfilled function (degree of functional performance less than 100 percent)
- Unnecessary function

Typical questions to determine the degree of functional performance are:[132]

- Is the effort to fulfill a function appropriate in comparison to the effort for other, more important or less important functions of the object?
- How much money is the customer willing to pay for this function group? What does it cost the organization? What contribution margin brings an additional offered function?
- What does the function group cost, if the proposal x, y or z is realized?
- What items or components can be eliminated if the functions have not been fulfilled?
- What operations may be omitted or simplified?
- What are the function costs for competitor solutions?

The results of the critical examination are summarized in the requirements specification sheet. The outcome of the assessment of the degree of functional performance is the starting point for the subsequent search for solutions.[133]

Detailed Objectives

Functional targets can be derived from the FA of the actual situation and the determination of the degree of functional performance. Likewise, the cost targets are formulated from the budgeted cost. The detailed objectives are defined by considering the initial situation and the general objectives. Further assessment criteria that allow the evaluation of the different solution concepts are established. The early specification of evaluation criteria contributes to a more objective

[130] Cf. VDI (2011), pp.46-47
[131] Cf. Prommer (2010), p.25
[132] Ibidem
[133] Cf. Prommer (2010), p.25

evaluation of the solutions. Examples of assessment criteria are; e.g. lowest cost or effort; originality of solution and environmental manufacturing process.[134]

2.11.6 Work Step 5 “Gathering and Creation of Solution Ideas“

During this phase of the VA approach, the consistent use of human creativity is important. Brainstorming and other creativity techniques help to provide different solution ideas. To get the best results, it is crucial that no early reviews are carried out. It is possible to combine solution ideas in the form of morphological matrices in order to find alternative solutions.[135]

Methodical tools that can be used are brainstorming methods, benchmarking, and lateral thinking in best practice direction.[136]

2.11.7 Work Step 6 “Evaluation of Solution Ideas”

After the creative identification of solution ideas in work step 5, the assessment phase of solution ideas begins. According to the principle, “from general to detail”, a systematic evaluation of all solution ideas needs to be carried out. Additionally, the compliance of reasonableness, feasibility, implementation risk, cost and efficiency must be reviewed.[137]

Methodical tools, which are useful within work step 6 are, for example, Utility analysis, Cost-Benefit analysis, feasibility studies, Break-Even-Point analysis or FMEA[138]

2.11.8 Work Step 7 “Development of Global Proposals“

A global proposal combines the solutions that are positively rated. Therefore it is necessary for the individual solution recommendations to complement each other.[139]

In the documentation, every solution suggestion must include the following data:[140]

- Description of the actual situation and recommended solution
- Required investment costs

[134] Cf. Bronner (2006), pp.24-25
[135] Cf. VDI (2011), p.49
[136] Cf. VDI (2011), pp.49-50
[137] Cf. Pauwels (2001), pp.79-80
[138] Cf. VDI (2011), p.50
[139] Ibidem
[140] Cf. VDI (2011), pp.50-51

- Cost and contribution margin improvement
- Improvements in quality, market and time benefits
- Risk assessment
- Estimated time of implementation

Methodical tools to be used are specifications for execution requirements, action plans and mind maps.[141]

2.11.9 Work Step 8 "Presentation of Proposals"

A complete documentation of the solution concept has to be prepared in this work step. After the presentation of the solution concept to the client, or top management and their critical questioning, the authorized person or committee makes the decision on the implementation.[142]

2.11.10 Work Step 9 "Implementation"

The realization of the final solution concept can take place if the contracting authorities decide to implement the presented and documented concept into practice. The specifications for execution requirements include the action plan and all relevant data. It makes sense to make another project team responsible for the implementation process.[143] Each project officially ends with a final report, which contains the results of the project compared to the defined targets.[144]

Methodical tools, which are useful, are Project Management, Project controlling, team-building or Simultaneous Engineering.[145]

2.12 Value Analysis and Diploma Project

For a meaningful application of the method Value Analysis (VA), a project has to comply with certain requirements. In Chapter 2.3, the areas of application and in chapter 2.4, crucial selection criteria for the usage of VA are described. In this section the prerequisites are aligned with the diploma project. Thus, it is argued that

[141] Cf. VDI (2011), p.51
[142] Cf. Pauwels (2001), p.85-86
[143] Cf. VDI (2011), pp.51-52
[144] Cf. Bronner (2006), p.42
[145] Cf. VDI (2011), p.52

VA is an appropriate instrument for this project and that good results can be expected.

The practical application of VA is a value improvement process of selected components of a motorcycle engine. The costs of applying VA must be amortized over a reasonable period of time. The cost of a graduate student, who takes on the complete planning and execution of the VA project, are comparably low. Of course, the required capacity of the project team members, who are integrated into the VA project, need to be considered as well. Their effort, however, should be limited.

A decisive factor for the client is the price. The cost of the benchmark engine is quite low and accordingly, the target prices for the new engine parts are kept down. The target price of the XY150 engine can probably not be achieved within the given requirements. However, the usage of VA promises high cost savings and its application is therefore definitely useful. In the best case scenario, the challenging cost targets can be achieved.

Furthermore, the optimization of manufacturing and assembling processes results in cost savings. The quantity of engines produced will be 12,000 units per year. In total, a lot of money can be saved due to an optimized design and the reduction of machining directions after the positive conclusion of the VA project.

An engine is a highly complex product and this circumstance also validates the application of VA. Even though a selection criterion states that for the usage of VA, a solution concept should not already exist, the application of VA is appropriate in this case because there are many options on how to desgin engines. A noticeable optimization of selected engine parts should be achieved with the application of VA.

2.13 Summary

Value Analysis (VA) is a successful approach for the development and improvement of products and services. Due to its five characteristics concept of function, concept of value, holistic approach, strong involvement of people and their behaviour and interdisciplinary teamwork, VA provides excellent conditions to meet the requirements of the development process and of the product or service itself. By following the linear procedure of the VA work plan and the integration of various management tools, within the ten work steps, it is possible to reach the specified objectives in terms of costs, time, quality and functionality.

3 Management Tools and Useful Techniques

Out of the wide range of applicable management instruments and useful techniques, there are a few tools used in in the VA project at FVT. These tools and techniques are described in detail in the following section. Further explanations to other usable methodical instruments can be found in literature.

3.1 ABC Analysis

The ABC analysis originates in the support of the disposition of consumables. The ABC analysis is a method that helps to order and classify large amounts of data. All elements within the data are assigned to the three classes A, B and C.[146] The typical distribution of A, B and C parts can be seen in Table 5.

Class	Value Percentage*
A	70 - 80 %
B	10 - 20 %
C	5 - 10 %

*Each company determines the percentage individually

Table 5: Typical Distribution of A, B and C Parts[147]

The application of the ABC analysis is very versatile due to its simple logic and its independence from specific investigation objects. The benefits of the ABC analysis are the reduction of complexity of large data sets and the simple application, without any dependency on specific contents of the analysis elements. The ABC analysis also makes prioritization of resources possible. It is assumed that comparable data (e.g. sales, part costs) is available and indeed ideally from different periods in order to understand possible dynamics in the analysis.[148]

First, the characteristics to be considered are defined and the related data is presented in tabular form. Then, the elements are sorted according to one

[146] Cf. Schawel/Billing (2012), p.13
[147] Cf. Pauwels (2001), p.130 (own illustration)
[148] Cf. Cordts/Lensing (1992), pp.1-2

characteristic and their values are accumulated in a new column. The last step involves the classification of the characteristic and the graphical representation. The result can be used to prioritize the resources.[149] Fig. 13 shows a typical “ABC-curve”.

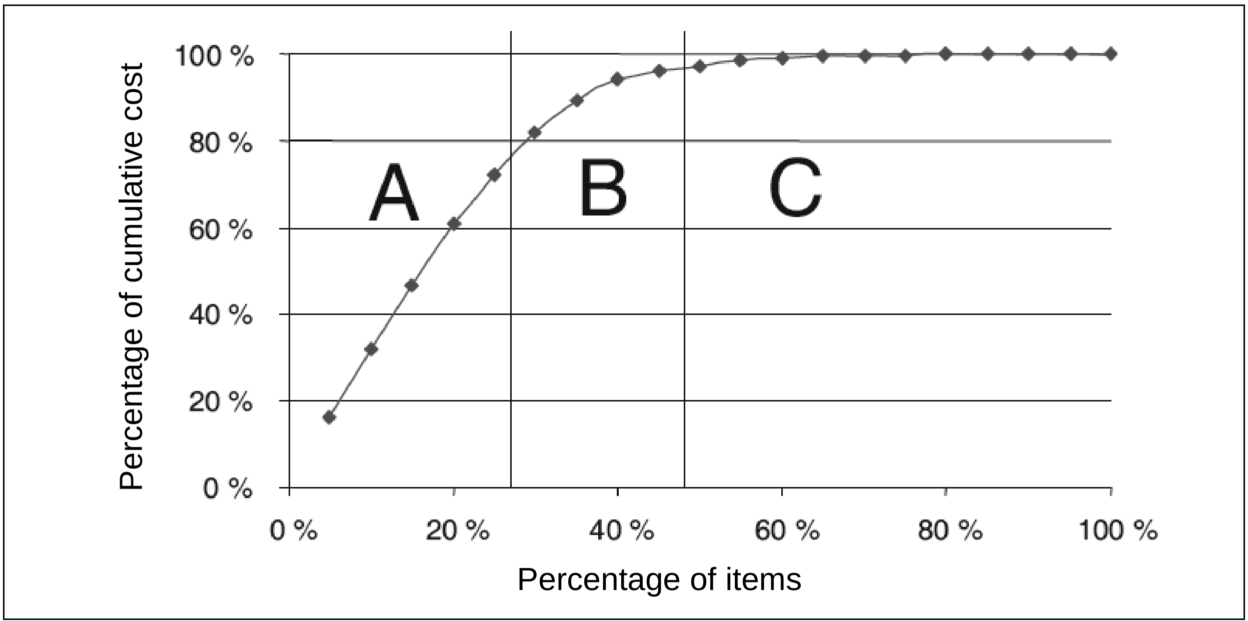

Fig. 13: ABC Analysis[150]

The ABC analysis can be used in work step 0 “Preliminary Phases” and in work step 4 “Functional Analysis, Cost Analysis, Detailed Objectives”.

3.2 Benchmarking

Benchmarking includes the systematic comparison of companies, business units, processes or products with internal or external objects. If a company wants to understand the areas in which operational performance is better, or worse, than that of comparable business units and what the differences are, this method is used once or continuously. Benchmarking provides the opportunity for internal and external learning and the possibility to identify potentials for optimization. This method may also be used as a basis for internal competition and continuous improvement.[151]

Requirements for benchmarking are the clear demarcation of the examination objects and the access to comparable objects. Benchmarking partners or competitors have to be motivated to participate because in the end, all participants benefit from the

[149] Cf. Schawel/Billing (2012), p.14
[150] Cf. Schawel/Billing (2012), p.15
[151] Cf. Siebert/Kempf (1998), pp.15-16

study. Furthermore, functional experts and people who are directly affected need to be involved. It must be possible to explain the differences in performance (e.g. efficient use of resources).[152] Benchmarking can be divided into four basic phases. These phases are explained in Fig. 14.

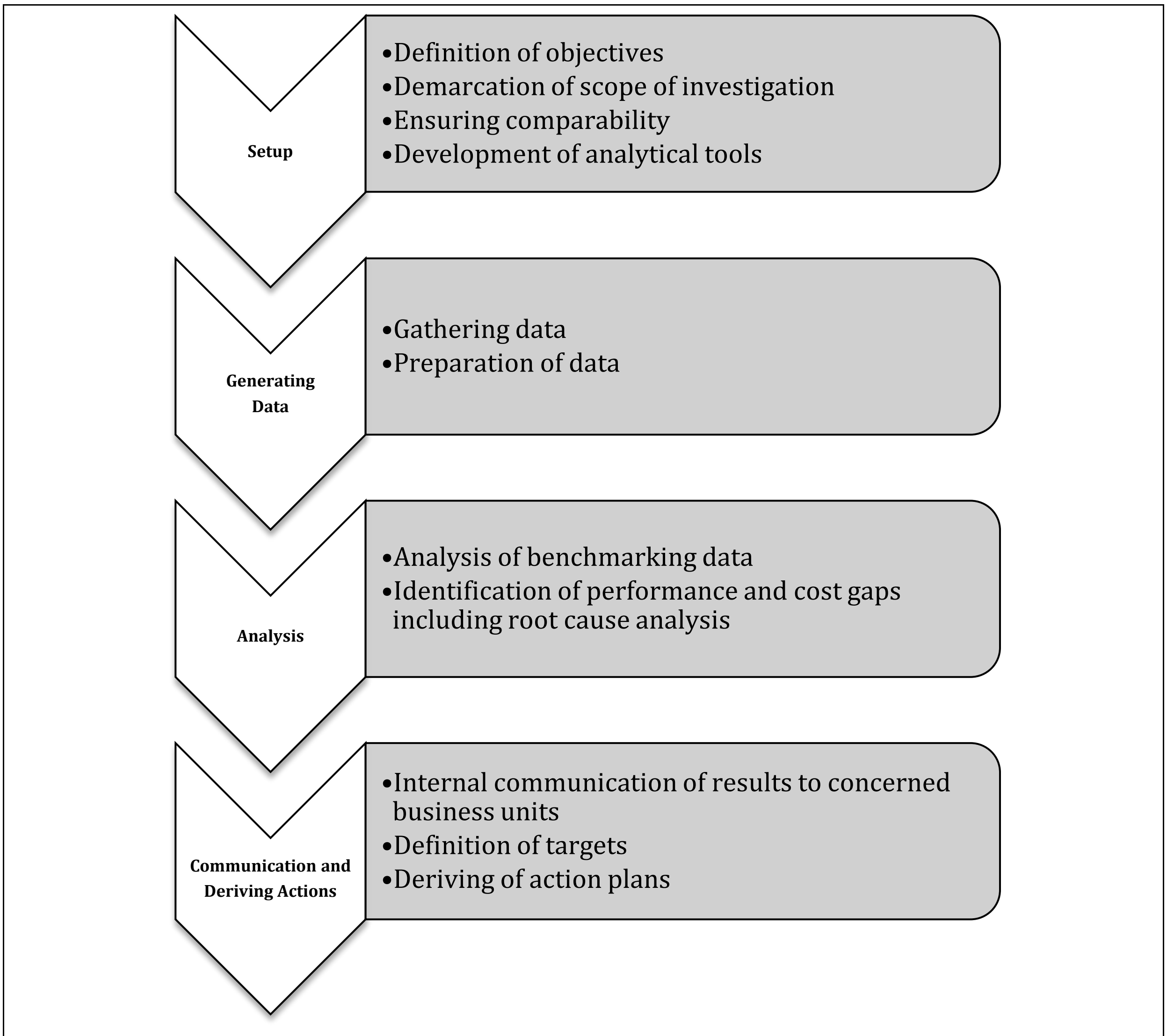

Fig. 14: Process of Benchmarking and Typical Tasks[153]

Benchmarking can be used in work step 1 “Project Definition”, work step 3 “Gathering Comprehensive Data” and work step 4 “Functional Analysis, Cost Analysis, Detailed Objectives”.

[152] Cf. Schawel/Billing (2012), pp.36-37
[153] Cf. Schawel/Billing (2012), p.36 (own illustration)

3.3 Preparation of Workshops

Good preparation can significantly increase the success of a workshop. The following checklist of activities may be useful for increasing the effectiveness and efficiency of workshops. The activities on the checklist are applicable, quite generally, for any kind of meeting. The more important the meeting is, the more extensively the activities should be performed. The advantage lies in the effective and efficient carrying out of meetings, increased results orientation, greater participant satisfaction and meaningful time use.[154]

The following tasks should be performed for workshop preparation:[155]

- *Definition of objectives:* The objectives of the meeting should be concise and precise. Clearly defined objectives are also helpful for preparation of the workshop. Presentation of the objectives creates common expectations of the meeting itself amongst participants. A maximum of three goals should be established for one meeting. Participant contribution varies throughout the meeting, depending on the formulation of the objectives.

- *Determining the participants:* The group of participants should be as small as possible but as large as necessary. Depending on the objectives, participants, who are capable of achieving the desired objectives should selected. Additionally, which participants will benefit themselves from the meeting may be considered.

- *Analysis of participants:* After selecting the group of participants, the opinions and attitudes of the individual participants towards each other and the subject need to be identified. This is so that the moderator is prepared for possible conflicts.

- *Setting of agenda:* The workshop topics must ordered logically. The agenda should start with the objectives of the meeting and end with the "next steps". This means that the meeting is not closed without a result.

The preparation of workshops needs to be done for all meetings, beginning with the kick-off meeting in work step 2 “Planning” up until the final presentation in work step 8 “Presentation of Proposals”.

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[154] Cf. Schawel/Billing (2012), p.162
[155] Cf. Schawel/Billing (2012), pp.163-164

3.4 SWOT Analysis

The SWOT analysis is a combination of an internal analysis (strengths and weaknesses) and external analysis (opportunities and threats) its goal is to determine the company's position within the market and to detect potentials for improvements. The SWOT analysis can be used in versatile ways. For example, the tool provides the basis for discussions about strategic positioning and possible developments of the company. The benefits of the SWOT analysis are the transparent visualization of strengths and weaknesses, in correlation with opportunities and threats of the market; the focuss on activities; the identification of actions and the preparation of a basis for strategic planning (e.g. enhancement of strengths, strengthen the weaknesses). Here, an exact demarcation of the object investigated and the relevant context are necessary prerequisites.[156]

The SWOT analysis includes an internal analysis and an external analysis. The internal analysis makes the strengths and weaknesses of a distinct objective more transparent. Every organization has its strengths (e.g. know-how in product development, brand and efficient production) and weaknesses (e.g. high fluctuation, very few innovations, non-robust production processes). But some of these are not as obvious as others. Therefore, strengths and weaknesses have to be seen from different perspectives. From an entrepreneur's point of view, the question is: "What are our core competences?" From a competitor's point of view: "Why should they fear us?" And from the customers' point of view: "Why should customers buy our products?" The external analysis determines the opportunities and threats, which could affect a company within a certain market segment. If the company is able to realize an opportunity within its strengths, the possibility for success is higher. Threats within a market could be a decrease of the product price or competitor consolidations.[157] Often, the results of the SWOT analysis are represented in a diagram (see Fig. 15).

[156] Cf. Wohinz (2003), p.77; Cf. Schawel/Billing (2012), pp.249-250
[157] Cf. Schawel/Billing (2012), p.250

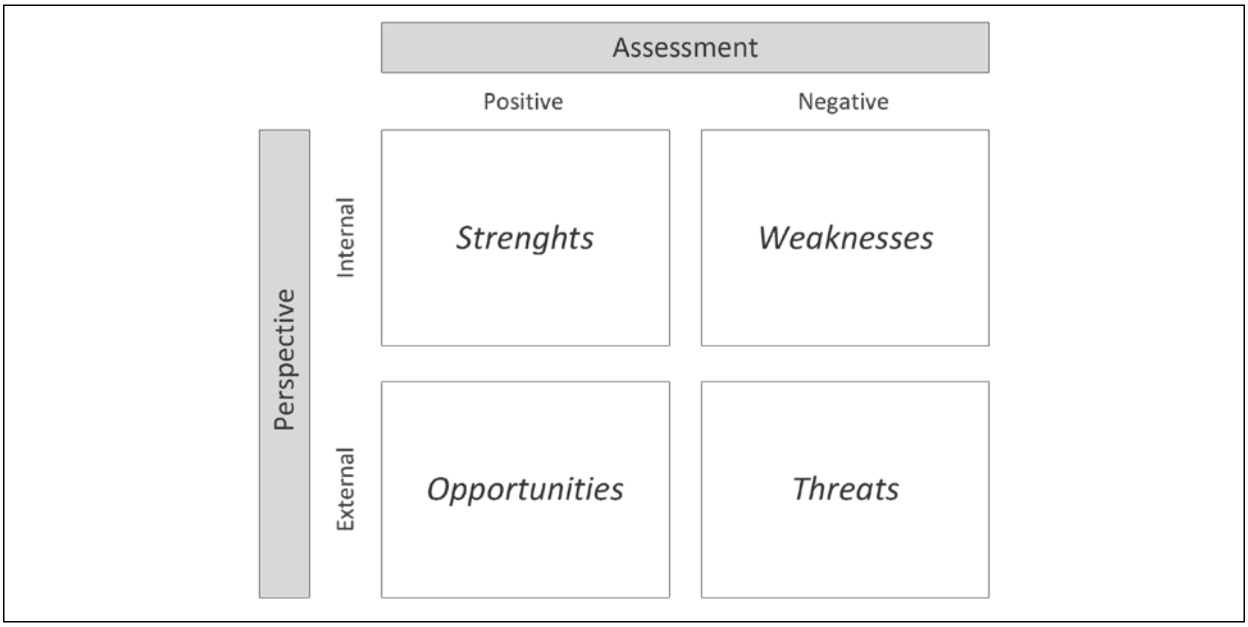

Fig. 15: SWOT Analysis[158]

The SWOT analysis can be used in work step 3 “Gathering Comprehensive Data”.

3.5 Target Costing

In conventional pricing for a product or service, the bottom-up calculation, by the addition of production costs and target return is used. In contrast, the target costing is based on a top-down approach. The target costs are calculated by starting from the possible market price, minus the target profit. If the drifting cost of the operational goods and services is higher than the target cost, actions need to be taken in the cost management.[159]

Typical application areas of target cost management are the development process for products and services, structuring and control of the production process and cost-cutting of current products. The benefits of target costing are the market focus in production processes and encourage business competitiveness. Furthermore, target costing helps to increase product profitability and supports the management in decision-making. Target costing requires a high cost transparency and its application must be very early in the product life cycle, as the following costs of service provision are largely defined in product design.[160]

[158] Cf. Schawel/Billing (2012), p.251
[159] Cf. Ehrlenspiel/Kiewert/Lindemann (2005), p.50
[160] Cf. Schawel/Billing (2012), pp.291-292

The target cost for the characteristics of a product is determined on the basis of market research. Simultaneously, a market-based, hyothetical sales price (target price), which the customer is willing to pay for the offered components is set. Subtracting the desired target profit form the target price results in the allowed costs by the market, the benchmark price (allowable cost). These costs are recognized as target costs and provide the budget for the product development process. The target costs reflect the market and customer requirements in a monetary way. The difference between target and drifting costs provides the target gap, which shows the quantitative need for action to reduce costs by means of appropriate measures.[161] The concept of target costing is schematically illustrated in Fig. 16.

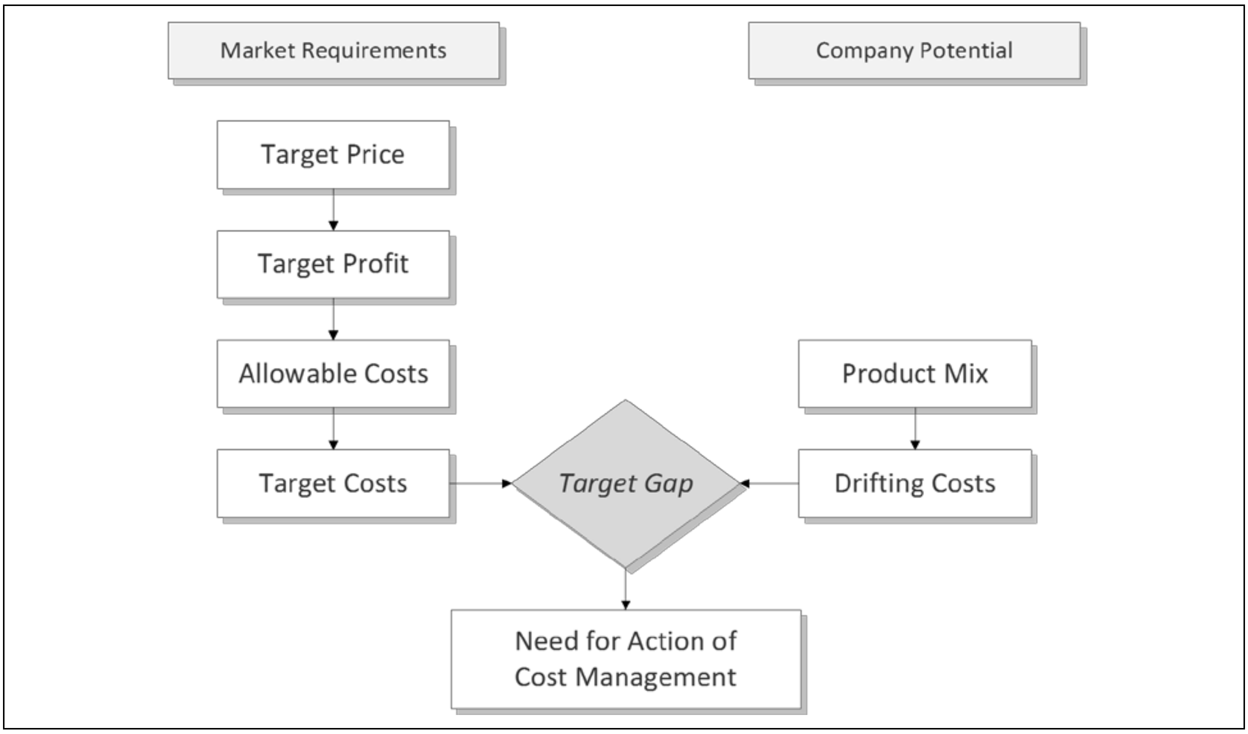

Fig. 16: The Concept of Target Costing[162]

The subjectivity in determining the target cost of products is especially considered to be a problem, since the target cost is not an objective quantity but dependent on subjective estimates, such as the estimated target price.[163]

Target Costing can be used at the end of work step 4 “Functional Analysis, Cost Analysis, Detailed Objectives” to determine the target cost of the VA object.

[161] Cf. VDI (2011), p.80
[162] Cf. VDI (2011), p.81
[163] Ibidem

3.6 Brainstorming

Brainstorming means that a group of several participants collects ideas on a topic - unstructured and without any comment. At the end of the short but intense session, a large number of ideas are usually present. After the brainstorming, the ideas are prioritized. Brainstorming is suitable for any kind of topic. One example would be the generation of new product ideas. Furthermore, Brainstorming promotes the development of entirely new ideas, since there is no restriction and various participants with different approaches are present.[164]

Certain rules should be kept in mind for a successful Brainstorming:[165]

- *Quantity over quality:* During the brainstorming session, the goal is to generate as many ideas as possible without direct assessment. The evaluation of ideas takes place afterwards.
- *No discussion or comment:* Brainstorming is purely the gathering of ideas. A discussion after the mention by and commentaries from others distract from the objective and should be prevented from the very beginning.
- *Short and intense:* The Brainstorming session should be relatively short but intense. In a group of five to six participants, 15 to 30 minutes may suffice entirely. The group should be divided up when consisting of about ten or more participants.

Firstly, the topic is worded very precisely so that all participants have the same understanding of the facts. The participants come up with key words for ideas. The moderator has a stack of index cards and notes each idea on a card. Alternatively, the ideas are collected on a flip chart, or the participants themselves write the ideas on a piece of paper. The advantage of the variant with the index cards is that the ideas can be easily sorted later on. The participants can either name entirely new ideas or build on previously mentioned ideas or modify them. The moderator must ensure that all participants mention ideas (e.g. quieter participants need to be asked explicitly for ideas). Only when the flow of ideas stops, should the moderator be slightly more active. There is the possibility to ask certain individuals or to pick

[164] Cf. Pauwels (2001), p.192
[165] Cf. Schlicksupp (1992), pp.104-107

mentioned ideas and ask for variations. In the end, all ideas can be looked through and completed.[166]

The Brainstorming method can be used in work step 5 “Gathering and Creation of Solution Ideas”.

3.7 Evaluation of Ideas

The outcome of a process for developing ideas (e.g. Brainstorming) is a long and unstructured list of ideas. The evaluation of ideas includes the structuring of this list and the systematic evaluation and prioritization of the developed ideas. The ideas can be evaluated by group participants or subsequent to the meeting, by a single person. The benefit is the establishment of transparency of the collected ideas through categorization into groups. A rating based on defined criteria identifies the most promising ideas. Prerequisites are the consistent elimination of redundant and weak ideas and the definition of criteria for the prioritization and structuring of the developed ideas.[167]

Depending on the scope of the problem, the ideas can be grouped under certain headings. The categorization has the advantage that these groups consist of a manageable number of ideas. Similar ideas can be identified more easily. Later on, the categories may be converted into work packages. For an initial evaluation, two dimensions can be used: impact and feasibility. Impact evaluates whether the idea has a significant effect on the solution of a problem and feasibility assesses whether the idea can be implemented with reasonable effort. With these two dimensions, a matrix can be formed and all ideas are assigned to their respective quadrant. After this rough evaluation of the promising ideas, they are evaluated under additional criteria (e.g. cost). So the ideas to be realized are filtered out.[168]

The evaluation of ideas needs to be done in work step 6 “Evaluation of Solution Ideas”.

[166] Cf. Wack et al. (1993), pp.31-32; Cf. Schawel/Billing (2012), pp.45-46
[167] Cf. Schawel/Billing (2012), p.120
[168] Cf. Pauwels (2001), p.83; Cf. Schawel/Billing (2012), pp.121-122

3.8 Summary

Value Analysis (VA) uses various management tools and useful techniques within the ten work steps to reach the specified objectives in terms of costs, time, quality and functionality. Chapter 3 describes the ABC analysis, Benchmarking, preparation of workshops, SWOT analysis, Target Costing, Brainstorming, and evaluation of ideas. These management tools and techniques are used within the VA project.

4 Value Analysis Project

This chapter describes the application of Value Analysis (VA) to selected components of a motorcycle engine. So the newly designed parts are optimized in terms of functionality and cost and are compared with an existing engine for benchmarking reasons. To ensure a structured proceeding of the VA project, the work plan according to EN 12973 is used. All performed tasks are described in the following sections and allocated to the respective steps of the work plan. Generally, information given in this chapter relies on the expertise and experience of the project team members.

4.1 Work Step 0 “Preliminary Phases“

Selected components of a motorcycle engine should be optimized by the application of the method Value Analysis (VA). The objective is to increase the functionality of these parts, while keeping the cost targets in mind. Over the course of several workshops with a particular VA project team, potential savings are identified and a global solution concept is developed. This can be integrated into the final product. The VA project takes place at the Research Institute for Internal Combustion Engines and Thermodynamics (FVT).

The following list summarizes the interests of each party involved in the VA project:

- *Customer:* In addition to the acquisition of know-how in the design and development process of a motorcycle engine, the customer pursues the desire for a product that meets all specified requirements. For the customer, it is very important that the cost factor is always taken into account during the entire cooperation period. When carrying out a VA project, the consideration of costs is explicitly made. Although the requirement to keep the costs as low as possible is complied with. The planned amount of engines to be manufactured is 12,000 units per year. That means every single Euro saved per engine strongly affects the decrease of the overall cost. Even though the quantity of 12,000 units per year is relatively low. The development of the XY150 is a prestige project for the customer, as the XY150 is the first engine designed and manufactured by the customer itself.

- *FVT:* Through the VA project FVT expects that employee learning processes take place and also that all requirements are met to the satisfaction of the client. As a result of the learning processes, it is then possible to apply VA to other projects in the future. The application of VA and the related continuous and clear documentation of results, identifies areas for further development opportunities and potential for improvements that cannot be applied to this project, due to the specified framework conditions. As a result, FVT wants to have a newly designed motorcycle engine, which satisfies all stakeholders. The work with VA also promises improved communication processes between the project team members.

- *Project participants:* The team members get the opportunity to become acquainted with the method VA. The management tool Functional Analysis (FA) within the VA provides a better common understanding of the functions of the selected components. Additionally, VA encourages the communication and collaboration between the team members.

Project Leader and Value Analysis Moderator

Another task in work step 0 is the nomination of the project leader and the VA moderator. Both functions are assigned to the graduate student. Firstly, because the execution of these tasks is an essential part of the thesis work and secondly, the student is the only one within the design department of FVT with knowledge in the area of VA.

4.2 Work Step 1 “Project Definition”

As described in Chapter 2.11.2, first the object for the VA project must be selected and the framework for the study area needs to be determined. Afterwards, it is possible to derive quantifiable targets in accordance with the given requirements.

The beginning part of this chapter gives an overview on the cost estimation of the benchmark engine, Yamaha YZF125. Then, as a basis for the selection of potential components to be investigated, the prices of all the parts of the XY150 engine are collected in a spreadsheet. Subsequently, an ABC analysis is conducted to figure out, which engine parts have the greatest impact on the total cost of the engine. After the selection of the VA object and the demarcation of the study area, overall targets for the VA project are defined.

4.2.1 Cost Estimation Benchmark Engine

The engine of the Yamaha YZF125 motorcycle was dismantled and all subassemblies and components were analysed and tested for benchmarking. Also, a cost estimation for the engine was done in consideration of material, weight, machining directions and standard prices of comparable subassemblies and components. The company, IMT-C (Innovative Motor Vehicles and Technology – Cooperation GmbH) carried out the cost estimation of the YZF125 engine. ITM-C provides a wide range of engineering and prototype services and this company manufactures the first prototypes of the new developed XY150 engine. FVT and ITM-C had already worked together on previous projects. The cost estimation for the Yamaha YZF125 engine (see Table 6) is the sum of the most expensive assemblies of a motorcycle engine, which is 548.50 EUR in total. The values are based on European manufacturing prices that are approximately 30 percent higher than in Asia. Also, Table 6 displays an estimation of the tools and machines needed for mass production of the engine.

Pos.	Designation	Part Cost	QTY	Overall Price	Tools & Machines	Tool Cost
1	Cylinder head, casting part	€ 25.00	1	€ 25.00	Double low pressure die casting	€ 170,000
2	Cylinder head, machining	€ 30.00	1	€ 30.00	Processing appliance	€ 50,000
3	Valve seat	€ 2.50	4	€ 10.00	Force fitting appliance	€ 10,000
4	Valve spring and carrier			€ -		
5	Rocker arm (incl. machining)	€ 10.00	2	€ 20.00	Forging tool and processing appliance	€ 20,000
6	Camshaft (incl. machining)	€ 30.00	1	€ 30.00	Sand casting installation and processing appliance	€ 35,000
7	Timing chain		1	€ -		
8	Chain tensioner		1	€ -		
9	Cylinder head cover	€ 3.50	1	€ 3.50	Double die casting	€ 35,000
10	Cylinder with greycast inlay, machined	€ 27.00	1	€ 27.00	Double die casting and processing appliance	€ 170,000
11	Crankcase left and right, casting part	€ 35.00	1	€ 35.00	Single die casting tool	€ 300,000
12	Crankcase left and right, machining	€ 24.00	1	€ 24.00	Processing appliance	€ 140,000
13	Clutch cover, casting part	€ 10.00	1	€ 10.00	Double die casting tool	€ 90,000
14	Cutch cover, machining	€ 6.00	1	€ 6.00	Processing appliance	€ 25,000
15	Generator cover, casting part	€ 7.00	1	€ 7.00	Double die casting tool	€ 30,000
16	Generator cover, machining	€ 3.50	1	€ 3.50	Processing appliance	€ 20,000
17	Crankshaft, complete	€ 73.00	1	€ 73.00		
18	6-speed gearbox, shafts and gears	€ 85.00	1	€ 85.00		
19	Generator, complete	€ 40.00	1	€ 40.00		
20	Electric starter	€ 10.00	1	€ 10.00		
21	Shifting drum	€ 12.00	1	€ 12.00		
22	Shifting forks, machined	€ 3.50	3	€ 10.50		
23	Balance shaft, machined	€ 12.00	1	€ 12.00		
24	Clutch, complete	€ 50.00	1	€ 50.00		
25	Water pump, complete	€ 25.00	1	€ 25.00	Tools	€ 60,000
			TOTAL	**€ 548.50**		**€ 1,155,000**

Table 6: Cost Estimation Benchmark Engine (Yamaha YZF125)[169]

4.2.2 First Part Cost Estimation for XY150

To gain an overview of the part costs, all parts used in the engine design are listed in a spreadsheet and sorted into groups. Available vendors provide the price data. Prices of newly designed parts and assemblies are estimated or assumed according to prices of similar existing components.

[169] Cf. FVT (2012e), p.52

Table 7 shows the target prices for the transmission assembly parts of the XY150.

No.	Item	QTY	Part	Target Price [EUR]
G	**TRANSMISSION**			**€ 47.92**
1	Shaft transmission input, 10T	1	New	€ 6.77
2	Gear input 5th, 21T	1	Standard	€ 2.92
3	Ring-snap d18.5	6	Standard	€ 0.41
4	Gear input 3rd & 4th, 20T and 22T	1	Standard	€ 5.57
5	Gear input 6th, 22T	1	Standard	€ 2.92
6	Gear input 2nd, 17T	1	Standard	€ 1.82
7	Ring-snap	1	Standard	€ 0.09
8	Gear output low, 27T	1	Standard	€ 3.70
9	Gear output 5th, 20T	1	Standard	€ 4.54
10	Washer, toothed, 20.3x24x0.5	2	Standard	€ 0.08
11	Gear output 3rd, 26T	1	Standard	€ 2.64
12	Washer, 20.5x25.5x0.5	1	Standard	€ 0.03
13	Gear output 4th, 24T	1	Standard	€ 2.62
14	Gear output top, 19T	1	Standard	€ 4.54
15	Gear output 2nd, 29T	1	Standard	€ 2.50
16	Shaft transmission output	1	Standard	€ 4.84
17	Collar, sprocket	1	Standard	€ 0.40
18	Ring-O, 17.5x1.5	1	Standard	€ 0.02
19	Sprocket output, 14T	1	New	€ 1.45
20	Plate sprocket	1	Standard	€ 0.03
21	Bolt-socket M6X10	2	Standard	€ 0.05

Table 7: Cost Estimation for the Transmission Assembly of the XY150[170]

Such a table is made for all sub assemblies of the engine. The sum of the prices of the single parts gives the target price of the sub assembly. An overall table with the target prices of all sub assemblies can be seen in Table 8. After the first estimation, the overall price for the XY150 motorcycle engine in mass production is 657.24 EUR.

[170] Data provided by customer (own illustration)

No.	Subassembly	Target Price [EUR]
A	Cylinder head	€ 54.58
B	Cylinder, piston	€ 29.71
C	Valve	€ 28.97
D	Camshaft, tensioner	€ 44.67
E	Crankshaft	€ 58.19
F	Clutch	€ 45.38
G	Transmission	€ 47.92
H	Gear change drum, shift fork	€ 18.17
I	Crankcase	€ 53.81
J	Engine cover	€ 29.90
K	Oil pump	€ 7.00
L	Generator	€ 29.53
M	Ignition system	€ 5.01
N	Starter motor	€ 32.93
O	Gear change mechanism	€ 4.29
P	Kick start mechanism	€ 11.16
Q	Intake system & EFI	€ 84.36
R	Radiator & water pump	€ 54.34
S	Exhaust	€ 17.33
	TOTAL	**€ 657.24**

Table 8: Target Prices for all Subassemblies of the XY150[171]

Table 9 illustrates the cost estimation of some YZF125 engine parts and subassemblies in comparison to the estimated target prices of the XY150 engine. To make the values comparable, all subassemblies and parts of the benchmark engine cost estimation are reduced by 30 percent because the target prices of the XY150 engine are based on Asian manufacturing and purchasing prices. It can be seen that most part prices are quite close to each other but some are not. For example, the price difference for the clutch due to the fact that for the YZF125, only the manual clutch is considered, while the XY150 price also includes the centrifugal clutch. The usage of different transmissions for the YZF125 and the XY150 are the reason for the cost difference of the transmission assembly. The column “Pos.” refers to the position number of the part in Table 6.

[171] Data provided by customer (own illustration)

Part	Target Price [EUR]	Cost Estimation Benchmark Engine	
		Overall Price (incl. machining)	Pos.
Cylinder head	€ 44.40	€ 38.50	1,2
Cylinder	€ 20.42	€ 18.90	10
Rocker arm / Cam follower	€ 13.78	€ 14.00	5
Camshaft	€ 12.73	€ 21.00	6
Crankshaft (complete)	€ 60.85	€ 59.50	17,23
Clutch	€ 54.36	€ 35.00	24
Transmission	€ 47.83	€ 59.50	18
Gear change drum, shift fork	€ 15.48	€ 15.75	21,22
Crankcase	€ 41.48	€ 41.30	11.12
Engine cover	€ 14.80	€ 18.55	13,14,15,16

Table 9: Cost Comparison of Engine Parts[172]

4.2.3 ABC Analysis of Engine Parts

Due to the huge number of subassemblies and single parts of the complete engine, the cost data is quite confusing. Important parts concerning impact on overall costs cannot be identified easily. Thus, an ABC analysis is carried out in order to obtain a more structured view on costs. With this method, it is possible to identify parts, which have significant impact on the overall costs.

Firstly, all parts of a motorcycle engine (over 450 parts in total) are listed in a spreadsheet and sorted by their price. The list with the most valuable parts can be seen in Table 10. The newly designed parts are displayed on a grey background, while the bought-in parts are displayed on a white background.

[172] Data provided by customer and IMT-C (own illustration)

Item	QTY	Price (EUR)		Remarks	Percentage	
		Per Unit	TOTAL		Per Item	Accum.
Throttle Body Assy	1	€ 47.39	€ 47.39	Common Part	7.93%	7.93%
Cylinder Head	1	€ 44.40	€ 44.40	New Design	7.44%	15.37%
Brush (Starter Motor)	1	€ 24.32	€ 24.32	Common Part (YZF125)	4.07%	19.44%
Rotor Assy and Stator Assy	1	€ 24.14	€ 24.14	Available	4.04%	23.48%
Cylinder	1	€ 20.42	€ 20.42	New Design	3.42%	26.90%
Radiator Shroud Assy	1	€ 20.42	€ 20.42	Standard Part	3.42%	30.32%
Crankcase (Right)	1	€ 14.80	€ 14.80	New Design	2.48%	32.80%
Muffler Assy	1	€ 14.12	€ 14.12	New Design	2.36%	35.16%
Crankcase (Left)	1	€ 14.05	€ 14.05	New Design	2.35%	37.51%
Primary Driven Gear	1	€ 13.58	€ 13.58	Modified Gear	2.27%	39.79%
Balance Shaft Pinion	1	€ 9.55	€ 9.55	New Design	1.60%	41.39%
Balance Shaft Gear	1	€ 9.55	€ 9.55	New Design	1.60%	42.99%
Clutch Cover	1	€ 8.78	€ 8.78	New Design	1.47%	44.46%
Pipe 1	1	€ 7.27	€ 7.27	Standard Part	1.22%	45.68%
Pipe 2	1	€ 7.27	€ 7.27	Standard Part	1.22%	46.89%
Rocker Arm (Intake)	1	€ 6.89	€ 6.89	New Design	1.15%	48.05%
Rocker Arm (Exhaust)	1	€ 6.89	€ 6.89	New Design	1.15%	49.20%
Transmission Shaft Input	1	€ 6.77	€ 6.77	Common Part	1.13%	50.34%
Oil Pump Pinion	1	€ 6.68	€ 6.68	New Design	1.12%	51.45%
Camshaft	2	€ 6.37	€ 12.73	New Design	1.92%	53.37%
Generator Gear	1	€ 6.24	€ 6.24	Common Part (YZF125)	1.05%	54.42%
Water Pump Assy	1	€ 6.12	€ 6.12	New Design	1.03%	55.44%
Generator Cover	1	€ 6.02	€ 6.02	New Design	1.01%	56.45%
Clutch	1	€ 5.96	€ 5.96	Common Part (YZF125)	1.00%	57.45%
Gear Input 3rd & 4th	1	€ 5.57	€ 5.57	Standard Part	0.93%	58.38%
Balance Shaft	1	€ 5.46	€ 5.46	New Design	0.91%	59.30%
Timing Drive Sprocket	1	€ 5.37	€ 5.37	New Design	0.90%	60.19%
Oil Pipe	1	€ 5.31	€ 5.31	Standard Part	0.89%	61.08%
Tensioner Assy	1	€ 5.11	€ 5.11	New Design	0.86%	61.94%
Upper Chain Guide	1	€ 4.89	€ 4.89	New Design	0.82%	62.76%
Transmission Shaft Output	1	€ 4.84	€ 4.84	Standard Part	0.81%	63.57%
Oil Pump Assy	1	€ 4.71	€ 4.71	New Design	0.79%	64.36%
Gear Output 5th	1	€ 4.54	€ 4.54	Standard Part	0.76%	65.12%
Gear Output 6th	1	€ 4.54	€ 4.54	Standard Part	0.76%	65.88%
Chain, Camshaft	1	€ 4.50	€ 4.50	Standard Part	0.75%	66.63%
Sprocket	2	€ 4.24	€ 8.47	New Design	1.42%	68.05%
Radiator Mounting Bracket	1	€ 4.20	€ 4.20	Standard Part	0.70%	68.75%
Lower Chain Guide	1	€ 4.18	€ 4.18	New Design	0.70%	69.45%
Electric Starter	1	€ 4.08	€ 4.08	Common Part (YZF125)	0.68%	70.13%

Table 10: A-Parts of ABC Analysis[173]

To achieve the graphical distribution, it is necessary to display the parts in percentage on the x-axis and the total cost, also in percentage on the y-axis of the

[173] Data provided by customer (own illustration)

diagram. Both parameters represent the percentage of the whole amount, which is 100 percent for each. In Fig. 17, it can be seen that the displayed curve shows typical characteristics.

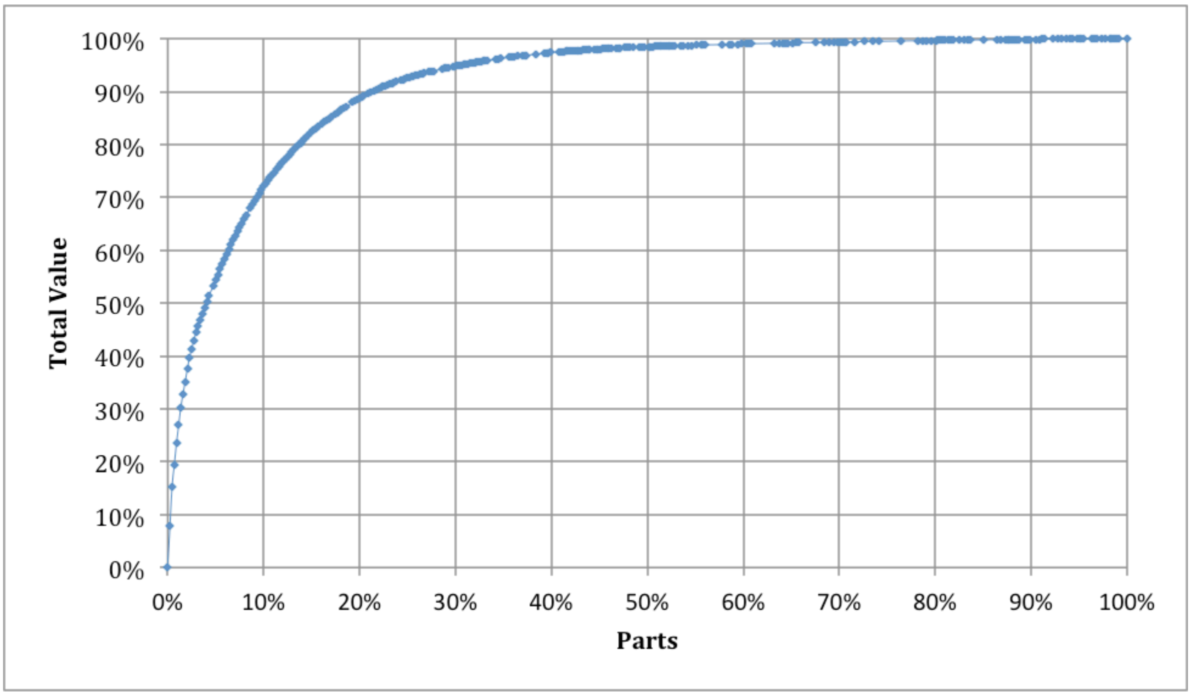

Fig. 17: Pareto Diagram of Engine Parts[174]

It turned out that about 14 percent of all engine parts represent nearly 80 percent of the total cost of one engine. About 40 percent of the 20 most valuable parts are bought-in parts. Negotiations with the suppliers of these parts may have a nameable impact on overall costs. The most expensive, newly designed parts are the cylinder head, the cylinder itself, the crankcase and the muffler.

Generally, it has to be stated, that the ABC analysis provides an image of the actual situation. At that moment, the basis for the analysis is the first cost estimation. Thus, there may be some changes in the ranking after the implementation of more precise costs.

4.2.4 Scope of Investigation

Ensuing from the ABC analysis, the scope of investigation was determined in consultation with the thesis supervisor and project leader of FVT. The entire cylinder head assembly was defined as VA object. The cylinder head assembly consists of

[174] Own illustration

the cylinder head itself, the cylinder head cover, the valve train including sprocket, camshaft and cam follower and the inlet and outlet valves. The following items are included in the VA object and specify the demarcation of the cylinder head assembly to adjacent components:

- Cylinder head gasket towards the cylinder
- Cylinder head and cylinder head cover to the outside
- Thermostat cover in the direction of water supply
- Intake flange in the direction of intake manifold
- Exhaust flange towards exhaust port

The following components are not included in the scope of investigation:

- Cylinder head bolts
- Cylinder head nuts
- Intake bolts
- Exhaust bolts
- Intake gasket
- Exhaust gasket
- Electronic Fuel Injection (EFI)

4.2.5 General Objectives

After the determination of the scope of investigation, the following general objectives are defined, which is also done in consultation with the thesis supervisor and project leader of FVT:

- Compliance with technical requirements
- Reduction of manufacturing costs
- Reduction of machining directions
- Facilitation of mounting

4.3 Work Step 2 “Planning”

The actual planning of the VA project starts with this step. This includes the formation of the project team, the preparation of the timetable and the setting up of work packages.

4.3.1 Selection of Team Members

For the execution of the VA, a project team is created mainly with employees from the design department of FVT, who are integrated directly in the motorcycle engine development project. The VA project team consists of the following people:

- *Thomas Böhm:* VA project leader and moderator; knowledge on the topic VA
- *Jürgen Tromayer:* project leader for the design and development of the new XY150 engine
- *Klaus Steinbrenner:* employee in the design department of FVT; experience in the area of design of engines
- *Simon Steidl:* student assistant; responsible for the design of the cylinder head assembly
- *Hans Peter Schnöll:* scientific assistant at IBL; experience in conducting VA

If it is necessary for specific tasks, or if certain information is required, it is possible to ask other experts at FVT or external people for their assistance.

4.3.2 Timetable

The initial work for this project began in early September 2012. In the first presentation, the VA method was presented to the project leader, as well as the first evaluation of costs and the outcome of the ABC analysis. Together with the project leader and the thesis supervisor, the VA object was selected and the study area was marked out. Furthermore, the team members were chosen. Shortly afterwards, the kick-off meeting with all involved team members took place at FVT. During the kick-off meeting, the VA project leader introduced the topic for the VA study to the team members. Additionally, the timetable and the work packages were set up. During the next workshop, at the end of November 2012, the functions of the cylinder head assembly were determined and structured in a function tree. Subsequently, the VA project leader created a function cost matrix and performed (in several individual meetings with the project staff) the percentage distribution of the component costs for the XY150 and the YZF125. The degree of functional performance was ascertained after structuring of the functions according to their impact on the overall costs of the cylinder head assembly. The target cost for the cylinder head assembly as a detailed objective was set after reviewing the function cost matrix and the assessment of the degree of functional performance. Then, in a discussion, all existing ideas were collected and evaluated. Due to the fact that the design phase for the motorcycle engine was almost finished at that point, the ideas were already implemented in the design of the XY150 cylinder head assembly. The integrated ideas were summarized in a global solution concept for the documentation. After all the performed activities and new insights were documented, the VA project was closed. The timetable is shown in Fig. 18.

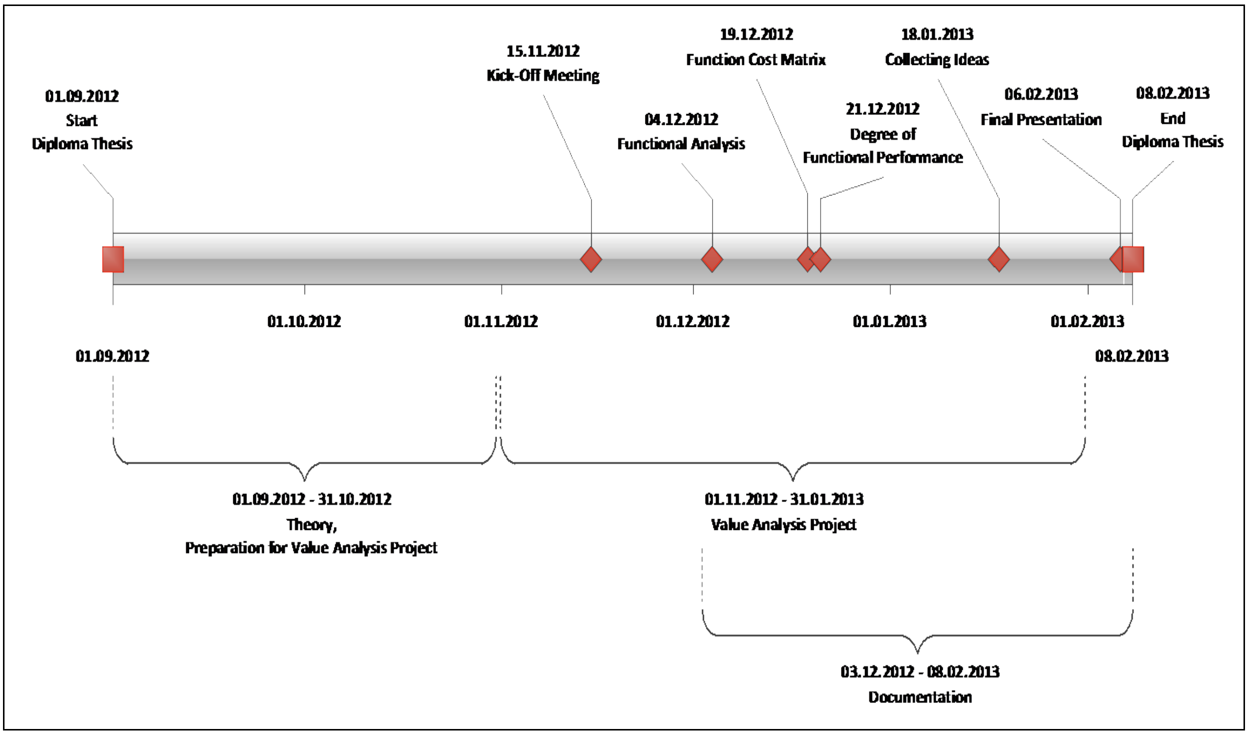

Fig. 18: Timetable for Value Analysis Project[175]

4.3.3 Work Packages

To ensure a structured approach, the VA project is divided into the following work packages in accordance with EN12973:

- Situation analysis
- ABC Analysis
- Gathering of relevant data
- SWOT Analysis
- Functional Analysis
- Function cost matrix
- Degree of functional performance
- Target Cost
- Collecting ideas
- Documentation of global solution concept

[175] Own illustration

4.4 Work Step 3 "Gathering Comprehensive Data"

In work step 3, the task is to collect all relevant data, necessary for the conduction of the VA project.

Progress of the Engine Design Project

During the initial work for this thesis, it could already be seen that the standard VA procedure would not be not possible for this project. The reason is that the design and development process of the XY150 cylinder head assemblies were already at a very advanced stage, when the VA project begun. However, the decision was made to continue with the VA project and to carry out the implementation of VA as well as possible according to the work plan. Mainly so that the project team members learn the proper and consistent execution of a VA project, so that the engineers can independently apply VA to another project in the future. New insights are gained due to the Functional Analysis of the cylinder head assemblies and the comparison of the function costs as well as the degree of functional performance between the YZF125 and the XY150, in work step 4. Previously integrated ideas for optimizng the XY150 cylinder head assembly are collected during work step 5. To conclude, the final concept and the optimizations in the new XY150 cylinder head assembly are presented. Also, it is stated how well the target costs are achieved by the XY150 cylinder head assembly.

4.4.1 Yamaha YZF125

For years, a derivate of the Yamaha YZF125 engine has been the best selling engine in the Asian region. In Asia, such a result can be directly aligned to the quality of a product. Especially compactness, long durability, low cost and easy maintenance are strengths of the YZF125 engine.

The cylinder head takes and positions all necessary elements of the cylinder head assembly. Even the water pump is connected to the cylinder head. The inlet for the secondary air supply is located at the cylinder head cover. The simple and compact design of the cylinder head assembly, including one camshaft, may not be achieveable for the newly designed XY150 cylinder head assembly. But the YZF125 engine cannot meet the criterion for fullfilling the EURO 5 emission standard. This requirement and the desire of the customer to realize its own engine were the base for the design of its own engine – the XY150. Fig. 19 is a picture of the cylinder head, including camshaft, rocker arms and intake and exhaust valves.

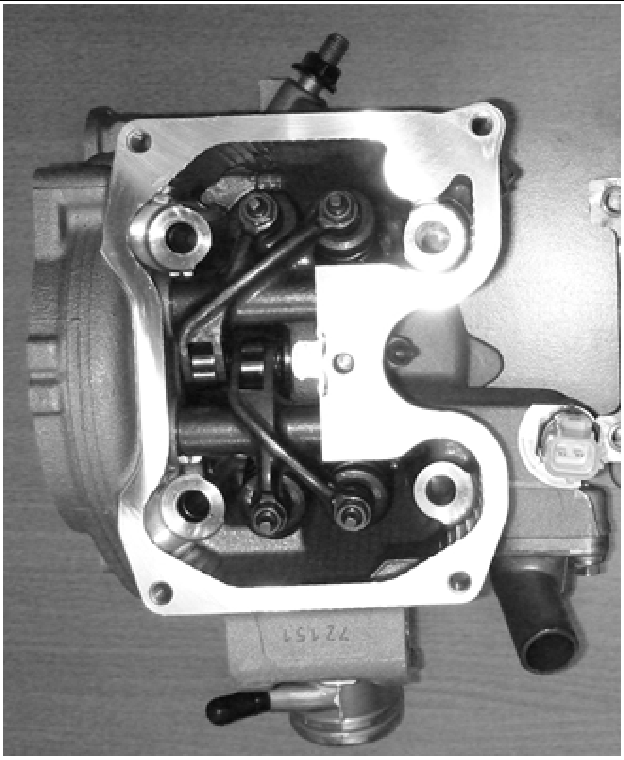

Fig. 19: Cylinder Head Assembly - YZF125[176]

Each component of the cylinder head assembly YZF125 that is relevant for the VA study and the respective cost, weight and material are listed in Table 11. The cost of some components are estimated by the prototype manufacturer ITM-C and the cost of the other parts are assumed in accordance with previously known prices of XY150 cylinder head assembly components. The costs are based on Asian market prices.

[176] Own illustration

Cylinder Head Assembly YZF125			Cost [EUR]		Weight [gram]		Material
No.	Component	QTY	Per Unit	TOTAL	Per Unit	TOTAL	
1	Cylinder head	1	€ 38.50	€ 38.50	1805	1805	Aluminum
2	Cylinder head gasket	1	€ 0.76	€ 0.76	5	5	Paper
3	Cylinder head center sleeve	2	€ 0.05	€ 0.10	2	4	Steel
4	Cylinder head cover	1	€ 2.50	€ 2.50	205	205	Aluminum
5	Cylinder head cover gasket	1	€ 0.80	€ 0.80	5	5	Rubber
6	Cylinder head cover bolt M6x15	5	€ 0.06	€ 0.30	5	25	Steel
7	Intake valve seat	2	€ 0.61	€ 1.22	7	14	Steel
8	Exhaust valve seat	2	€ 0.61	€ 1.22	6	12	Steel
9	Intake Valve	2	€ 1.78	€ 3.55	16	32	Steel
10	Exhaust Valve	2	€ 1.66	€ 3.31	14	28	Steel
11	Intake valve guide	2	€ 0.42	€ 0.84	15	30	Steel
12	Exhaust valve guide	2	€ 0.42	€ 0.84	15	30	Steel
13	Valve stem seal	4	€ 0.21	€ 0.84	1	4	Synthetics
14	Valve spring	4	€ 0.56	€ 2.25	22	88	Steel
15	Spring seat	4	€ 0.04	€ 0.16	4	16	Steel
16	Valve carrier	4	€ 0.27	€ 1.06	6	24	Steel
17	Valve carrier collet	8	€ 0.05	€ 0.37	0.3	2.4	Steel
18	Intake rocker arm	1	€ 8.50	€ 8.50	85	85	Steel
19	Exhaust rocker arm	1	€ 8.50	€ 8.50	87	87	Steel
20	Rocker arm shaft	2	€ 1.27	€ 2.53	30	60	Steel
21	Camshaft	1	€ 10.00	€ 10.00	194	194	Steel
22	Camshaft bearing 6906	1	€ 1.17	€ 1.17	33	33	Steel
23	Camshaft bearing 6001Z	1	€ 0.62	€ 0.62	19	19	Steel
24	Sprocket	1	€ 4.24	€ 4.24	67	67	Steel
25	Sprocket bolt M8x25	1	€ 0.07	€ 0.07	17	17	Steel
26	Sprocket pin	2	€ 0.10	€ 0.20	2	4	Steel
27	Locking plate	1	€ 2.00	€ 2.00	11	11	Steel
28	Locking plate screw M6x15	2	€ 0.06	€ 0.12	5	10	Steel
29	Decompressor	1	€ 5.00	€ 5.00	91	91	Steel
30	Spark plug NGK R	1	€ 6.00	€ 6.00	31	31	
31	Coolant temperature sensor	1	€ 1.84	€ 1.84	24	24	
32	Thermostat	1	€ 9.00	€ 9.00	32	32	
33	Thermostat cover	1	€ 2.00	€ 1.50	32	32	Steel
34	Thermostat cover bolt M6x20	2	€ 0.07	€ 0.14	6	12	Steel
35	Oil locking screw M6x15	1	€ 0.06	€ 0.06	5	5	Steel
36	Oil sealing washer	1	€ 0.10	€ 0.10	1	1	Copper
	TOTAL	70		€ 120.21		3144.4	

Table 11: Part List YZF125[177]

A detailed description of the components follows in section 4.5.2 in the preparation of the function cost matrix in order to make the distribution of the component costs to the functions easier to understand.

[177] Data provided by FVT (own illustration)

The part list consists of single parts, except decompressor and rocker arm. The decompressor basically consists of five parts (fly mass, draft, return spring, bolt, stop pin), which are grouped together in the decompressor subassembly. Then, the price of the decompressor is rated at 5.00 EUR. In the same way, six parts (rocker arm, roller pin, rolling body, roller, adjusting nut M5, adjusting screw) are grouped together in the rocker arm subassembly, which is price-rated at 8.50 EUR.

4.4.2 SWOT Analysis YZF125

A SWOT analysis is performed in order to gain an overview of the strengths, weaknesses, chances and threats of the YZF125 cylinder head assembly and also the complete engine. The following sections explain all considered facts.

Strengths (YZF125)

a. *Simple and compact design:* The SOHC (Single Overhead Camshaft) technology for actuating the valves allows a very simple and compact design by using very few parts.

b. *Durability and robustness:* The YZF125 is made to be robust and has a long lifespan.

c. *Proven System:* The YZF125 has already been in use for a long time and its strengths and weaknesses are quite well-known.

d. *Easy maintenance:* The adjustment of the valve clearance can be done with screws and nuts. Therefore each mechanic can do the setting very easily. Unfortunately, this technique leads to an increase of the moving masses. But considering only maintenance reasons, the use of screws and nuts for adjusting the valve clearance is a strength.

e. *Versatile use:* The YZF125 is used in a very versatile way, in several models, with different displacements.

f. *Lightweight:* The small number of components and the very compact design keeps the weight of the YZF125 cylinder head assembly low (compared to the XY150 cylinder head assembly nearly 1.5 kg).

g. *Good reputation:* The YZF125 has a very good reputation in Asia and is associated with high quality.

h. *Less prone to errors:* The YZF125 cylinder head assembly is less prone to errors and thus strengthens the trust of customers.

i. *Good value for money:* The YZF125 offers solid quality for a moderate price.

Weaknesses (YZF125)

a. *Inadequate cooling:* The cooling of the YZF125 in its present form allows no increase in power.

b. *High emission values:* The YZF125 has emission levels that only meet the EURO 3 standard.

c. *No appealing design:* Overall, the styling of the YZF125 engine is ok but a nice styling of the cylinder and cylinder head is missing.

d. *No overall concept:* The YZF125 engine has been modified and enhanced several times. However, the limits of possible modifications are already achieved.

e. *Old fashioned design:* The SOHC design does not match the current state of technology.

Opportunities (YZF125)

a. *Market leader:* The YZF125 is the best-selling motorcycle engine in its performance class in the addressed region.

b. *High name recognition:* Yamaha is a manufacturer that has a high degree of brand awareness.

Threats (YZF125)

a. *Development of competitive products:* The development of better products in the same performance segment represents competition for the YZF125.

b. *Legal rules change:* For example, the introduction of lower allowed emission values can be problematic for the YZF125 motorcycle engine.

Fig. 20 summarizes strenghts, weaknesses, opportunities and threats for the YZF125 in a represented figure.

Strengths	**Weaknesses**
a. *Simple and compact design* b. *Durability and robustness* *c. Proven System* d. *Easy maintenance* e. *Versatile use* f. *Lightweight* g. *Good reputation* h. *Less prone to errors* i. *Good value for money*	a. *Inadequate cooling* b. *High emission values* c. *No appealing design* d. *No overall concept* e. *Old fashioned design*
Opportunities	**Threats**
a. *Market leader* b. *High name recognition*	a. *Development of competitive products* b. *Legal rules change*

Fig. 20: SWOT Analysis - YZF125[178]

4.4.3 XY150

As mentioned in chapter 1.2, the XY150 has to meet certain requirements. Necessary requirements, which must be considered during the design and development phase of the cylinder head assembly are summarized in the following list:[179]

- Power (12kW)
- Engine speed (max. 12000rpm)
- Durability at the prototype testing (500h)
- Maintainability (utilize screws to adjust the valve clearance)
- Ensure sufficient and balanced cooling
- Emission standard EURO 5
- Compact and modern engine concept

[178] Own illustration
[179] Cf. FVT (2012b), p.18

- Sporty and robust design
- Muscular and performance oriented appearance
- High quality appearance
- Easy to manufacture at lowest possible cost
- Reliable and durable for daily use
- To utilize as many existing components of the customer as possible
- To utilize standard components from reputable suppliers or existing suppliers of the customer.
- To minimize the tooling development for standard parts

Based on these specifications and after long discussions, the customer and FVT have decided to deviate from the originally planned design of the cylinder head assembly with one camshaft, to use two camshafts (one intake and one exhaust camshaft) in the new XY150 concept. Respectively, the DOHC (Double Overhead Camshaft) technology provides a modern design of a cylinder head assembly and thus the requirements are met completely. Fig. 21 shows a picture of the newly designed XY150 cylinder head assembly.

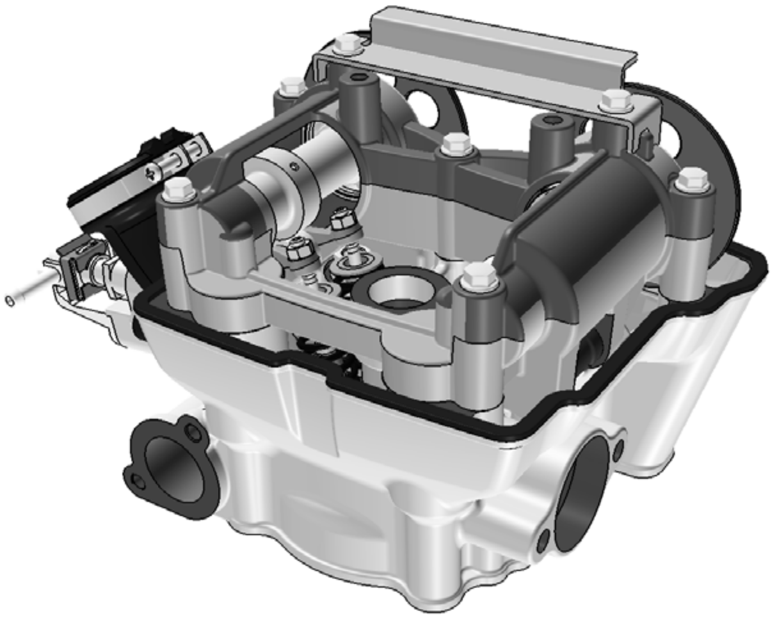

Fig. 21: Cylinder Head Assembly - XY150[180]

[180] Own illustration

Each component of the cylinder head assembly XY150 and the respective cost, weight and material are listed in Table 12 in the same way as is done for the YZF125 cylinder head assembly.

It can be seen that the YZF125 cylinder head consists of 70 parts, while the XY150 cylinder head assembly consists of 80 parts. There is a difference of 10 parts. Also, the difference in weight is shown. The weight of the YZF125 cylinder head assembly is 3144.4 grams and of the XY150 is 4640.4 grams, which results in a difference of 1496 grams. This means that the XY150 cylinder head assembly is 47.6 percent heavier than the YZF125 cylinder head assembly.

Cylinder Head Assembly XY150			Cost [EUR]		Weight [gram]		Material
No.	Component	QTY	Per Unit	TOTAL	Per Unit	TOTAL	
1	Cylinder head	1	€ 44.00	€ 44.00	1676	1676	Aluminum
2	Cylinder head gasket	1	€ 0.76	€ 0.76	5	5	Paper
3	Cylinder head center sleeve	2	€ 0.05	€ 0.10	2	4	Steel
4	Cylinder head cover	1	€ 4.00	€ 4.00	582	582	Aluminum
5	Cylinder head cover gasket	1	€ 1.00	€ 1.00	25	25	Rubber
6	Cylinder head cover bolt	2	€ 0.35	€ 0.70	20	40	Steel
7	Cylinder head cover washer	2	€ 0.05	€ 0.10	3	6	Rubber, Steel
8	Intake valve seat	2	€ 0.61	€ 1.21	7	14	Steel
9	Exhaust valve seat	2	€ 0.61	€ 1.21	6	12	Steel
10	Intake Valve	2	€ 1.78	€ 3.55	16	32	Steel
11	Exhaust Valve	2	€ 1.66	€ 3.31	14	28	Steel
12	Intake valve guide	2	€ 0.42	€ 0.84	15	30	Steel
13	Exhaust valve guide	2	€ 0.42	€ 0.84	15	30	Steel
14	Valve stem seal	4	€ 0.21	€ 0.84	1	4	Synthetics
15	Valve spring	4	€ 0.56	€ 2.25	22	88	Steel
16	Spring seat	4	€ 0.04	€ 0.16	4	16	Steel
17	Valve carrier	4	€ 0.27	€ 1.06	6	24	Steel
18	Valve carrier collet	8	€ 0.05	€ 0.37	0.3	2.4	Steel
19	Intake cam follower	1	€ 8.50	€ 8.50	68	68	Steel
20	Exhaust cam follower	1	€ 8.50	€ 8.50	68	68	Steel
21	Cam follower shaft	2	€ 1.27	€ 2.53	28	56	Steel
22	Intake camshaft	1	€ 6.37	€ 6.37	255	255	Steel
23	Exhaust camshaft	1	€ 7.20	€ 7.20	288	288	Steel
24	Camshaft bearing 6004	2	€ 1.17	€ 2.34	66	132	Steel
25	Camshaft bearing 6001Z	2	€ 0.62	€ 1.24	19	38	Steel
26	Camshaft carrier	1	€ 10.00	€ 10.00	583	583	Aluminum
27	Camshaft carrier center sleeve	2	€ 0.10	€ 0.20	12	24	Steel
28	Camshaft carrier screw M6x60	5	€ 0.08	€ 0.40	15	75	Steel
29	Sprocket	2	€ 4.24	€ 8.47	67	134	Steel
30	Sprocket bolt M8x25	2	€ 0.08	€ 0.16	17	34	Steel
31	Feather key	2	€ 0.12	€ 0.24	4	8	Steel
32	Chain guide	1	€ 3.00	€ 3.00	85	85	Steel
33	Chain guide screw M6x15	2	€ 0.06	€ 0.12	5	10	Steel
34	Decompressor	1	€ 5.00	€ 5.00	33	33	Steel
35	Spark plug NGK R	1	€ 6.00	€ 6.00	31	31	
36	Coolant temperature sensor	1	€ 1.84	€ 1.84	24	24	
37	Thermostat	1	€ 9.00	€ 9.00	32	32	
38	Thermostat cover	1	€ 2.00	€ 1.50	32	32	Steel
39	Thermostat cover bolt M6x20	2	€ 0.07	€ 0.14	6	12	Steel
	TOTAL	**80**		**€ 149.05**		**4640.4**	

Table 12: Part List XY150[181]

[181] Data provided by FVT (own illustration)

4.4.4 SWOT Analysis XY150

A SWOT analysis is performed in order to gain an overview of the strengths, weaknesses, chances and threats of the XY150 cylinder head assembly and also the complete engine. The following sections explain all considered facts.

Strenghts (XY150)

a. *Nice styling:* The XY150 engine stands out due to its appealing, sporty design and its noble coating.

b. *State of the art technology:* The design of the engine with two overhead camshafts (DOHC) meets the current state of technology.

c. *Ease of manufacture and assembly:* The XY150 cylinder head assembly can be easily produced (reduction of processing and machining directions). The mounting of the cylinder head assembly is facilitated by the camshaft carrier.

d. *Robust design:* The usage of roller bearings ensures that an emergency operation is possible with little oil in the engine.

e. *Outstanding durability:* The XY150 is designed to achieve 500 hours at the full load test, which is usually not common. Comparable engines are only subjected to a period of 250 hours to the full load test.

f. *Easy maintenance:* The adjustment of the valve clearance can be done with screws and nuts. Therefore, each mechanic can do the setting very easily. Unfortunately, this technique leads to an increase of the moving masses. But considering only maintenance reasons, the use of screws and nuts for adjusting the valve clearance is a strength.

g. *Modular design:* Due to the modular design principle, different performances can be achieved with the same cylinder head assembly.

h. *Low weight of moving masses:* In particular, the intake and exhaust cam follower are optimized compared to the YZF125, to ensure a low moment of inertia.

i. *Adequate and symmetrical cooling:* The cooling system ensures a very good heat removal from the combustion chamber area.

j. *Low emissions:* The exhaust emissions of XY150 should meet the EURO 5 standard.

k. *High performance and efficiency:* The XY150 is a modern engine that scores highly among customers, with its high performance and low fuel consumption (optimized channel geometry, high compression ratio, roller bearing to reduce internal friction).

Weaknesses (XY150)

a. *Large number of used components:* Due to the additional camshaft carrier and the DOHC technology, the XY150 cylinder head assembly has more components than other concepts.

b. *Large weight:* Due to the high number of components and the large dimensions, the cylinder head assembly is quite heavy. But there is no requirement to meet a light weight design.

Opportunities (XY150)

a. *Extension of the product portfolio:* The XY150, with its modular design, allows the customer to broaden its product portfolio with several models.

b. *Increase of name recognition and acquisition of new customers:* The XY150 is the first internal combustion engine, which is being developed by the customer. Until now, engines were only replicas or manufactured under license. The chance is that the customer is the first company that has not only manufactured but also designed and developed an engine in the addressed region. The new engine offers the possibility to increase the name recognition of the customer as well as the acquisition of new customers.

c. *Knowledge acquisition:* The common development process of the XY150 motorcycle engine of the customer and FVT generates know how for the customers' engineers.

d. *Production at own manufacturing facilities:* Except necessary supply parts all other components can be manufactured in the customers' own facilities and this serves to sustain employment.

Threats (XY150)

a. *New Engine:* The XY150 is a completely new engine and therefore no references exist.

b. *Risk of plagiarism and competitive products:* The XY150 is not protected against imitations.

c. *Infringement of patents:* The XY150 cylinder head assembly is constructed very close to the design of the Honda CBR250 from 2011. It may turn out that already existing patents are infringed.

d. *Modular design and modern technology is not honored:* Maybe the customer is not willing to pay a higher price for the increased benefits and the application of modern technology, when comparable models are very reliable too.

e. *Discovering severe errors during prototype testing:* It is possible that during prototype testing, it turns out that the design of the XY150 contains severe errors. The achievement of 500 hours at the full load test is especially a hurdle that must be overcome.

f. *Price too high:* It is expected that the XY150 engine is not among the cheapest in its performance segment. What is important is that the total price of the new motorcycle and whether the customer wants to pay that

Fig. 22 summarizes strenghts, weaknesses, opportunities and threats for the XY150 in a represented figure.

Strengths	**Weaknesses**
a. *Nice styling* b. *State of the art technology* c. *Ease of manufacture and assembly* d. *Robust design* e. *Outstanding durability* f. *Easy maintenance* g. *Modular design* h. *Low weight of moving masses* i. *Adequate and symmetrical cooling* j. *Low emissions* k. *High performance and efficiency*	a. *Large number of used components* b. *Large weight*
Opportunities	**Threats**
a. *Extension of the product portfolio* b. *Increase* of *name recognition and acquisition of new customers* c. *Knowledge acquisition* d. *Production at own manufacturing facilities*	a. *New Engine* b. *Risk of plagiarism and competitive products* c. *Infringement of patents* d. *Modular design and modern technology is not honored* e. *Discovering severe errors during prototype testing* f. *Price too high*

Fig. 22: SWOT Analysis - XY150[182]

[182] Own illustration

4.5 Work Step 4 “Functional Analysis, Cost Analysis, Detailed Objectives”

The Functional Analysis (FA) is executed within a workshop involving all project team members. All components of the cylinder head assembly were analysed and named with functions in advance. The VA project leader and a project team member announced a first rough structure. Thus, a good starting point for the workshop was provided. At the beginning of the workshop, the first approach of the function structure was reviewed by all project team members. After intensive discussions with adding, deleting, changing of naming of functions and modification of the abstraction level, a function tree was set up. Afterwards the project team decided, which functions are to be considered for the subsequent function cost analysis.

4.5.1 Functional Analysis and Function Tree

Fig. 23 illustrates the function tree, which was the outcome of the first workshop. This function tree is valid for both the YZF125 and the XY150 cylinder head assembly. Due to the high complexity of the VA object, the naming of functions and the structuring in the form of a function tree was a tough challenge for the project team.

The structuring of functions in the function tree is carried out according to logical criteria of main functions and auxiliary functions. Beside use functions, esteem functions are also considered. There are nine main functions and 22 auxiliary functions. The classification of the auxiliary functions is performed in several levels. In the numbering of the auxiliary functions, the number of the main function is in first place and the following points reflect the order of the subgroups of the auxiliary functions. E.g. auxiliary function “1.1.1. Pass fresh gas” is part of the main function “1. Exchange charge” and the auxiliary function “1.1. Supply fresh gas”.

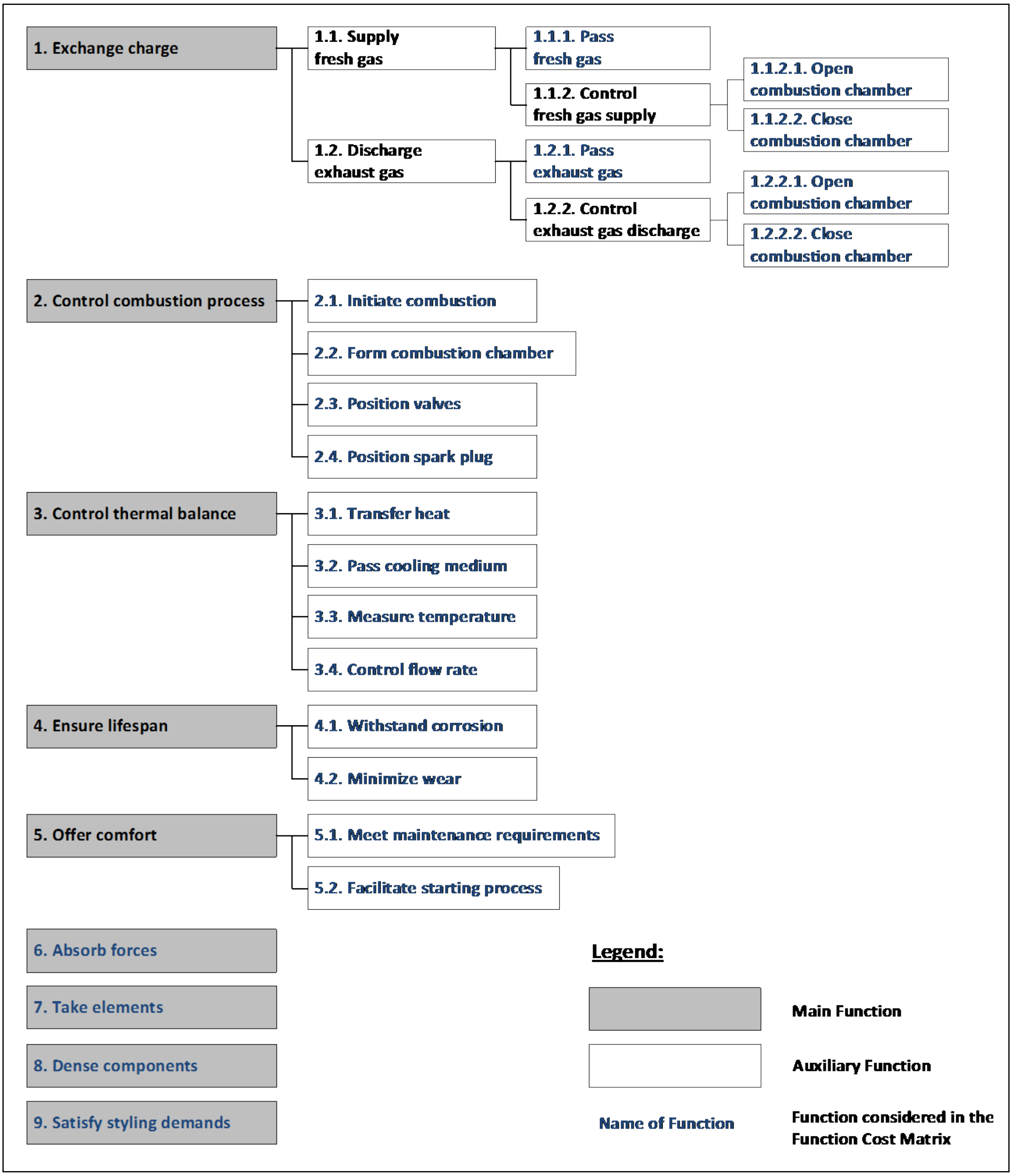

Fig. 23: Function Tree - Cylinder Head Assembly[183]

[183] Own illustration

Description of functions

1. ***Exchange charge:*** The cylinder head assembly performs and controls the charge exchange.

   1.1. ***Supply fresh gas:*** The cylinder head assembly supplies fresh gas in the combustion chamber.

   1.1.1. **Pass fresh gas:** The cylinder head passes fresh gas from the intake manifold into the combustion chamber.

   1.1.2. **Control fresh gas supply:** The quantity of supplied fresh gas and the timing of the supply must be controlled.

   1.1.2.1. ***Open combustion chamber:*** For the supply of fresh gas, the combustion chamber must be opened.

   1.1.2.2. ***Close combustion chamber:*** The combustion chamber must be closed so that pressure increase and combustion can take place.

   1.2. ***Discharge exhaust gas:*** The cylinder head assembly discharges the exhaust gas from the combustion chamber.

   1.2.1. **Pass exhaust gas:** The cylinder head passes exhaust gas from into the combustion chamber into the exhaust manifold.

   1.2.2. **Control exhaust gas discharge:** The timing and duration of the exhaust gas discharge must be controlled.

   1.2.2.1. ***Open combustion chamber:*** For the removal of exhaust gas, the combustion chamber must be opened.

   1.2.2.2. ***Close combustion chamber:*** The combustion chamber must be closed so that pressure increase and combustion can take place.

2. ***Control combustion process:*** In order to achieve performance and meet emission standards, the combustion process must be controlled.

   2.1. ***Initiate combustion:*** A very quick ignition is required for the combustion of the fresh gas.

   2.2. ***Form combustion chamber:*** The cylinder head forms a closed combustion chamber, in which the combustion of the fresh gas can take place.

2.3. ***Position valves:*** The cylinder head adjusts the valves to a beneficial position.

2.4. ***Position spark plug:*** The cylinder head adjusts the spark plug to a beneficial position.

3. ***Control thermal balance:*** The cylinder head assembly must allow the control of heat supply and heat dissipation.

3.1. ***Transfer heat:*** Heat is transferred via wall surfaces and components of the cylinder head assembly.

3.2. ***Pass cooling medium:*** The cylinder head passes the cooling medium to the hot spots and away again to enable heat dissipation.

3.3. ***Measure temperature:*** The temperature of the cooling medium is measured all the time to ensure temperature control.

3.4. ***Control flow rate:*** The flow rate of the cooling medium can be controlled in order to control the supplied and dissipated heat by the cooling medium.

4. ***Ensure lifespan:*** The cylinder head assembly needs to have a sufficient durability to ensure customer satisfaction.

4.1. ***Withstand corrosion:*** The parts of the cylinder head assembly must withstand corrosion.

4.2. ***Minimize wear:*** All moving parts must be wear resistant.

5. ***Offer comfort:*** To ensure customer satisfaction, all useable components must be easy and safe to handle.

5.1. ***Meet maintenance requirements:*** The possibility of maintenance with little effort needs to be ensured.

5.2. ***Facilitate starting process:*** The start of the motorcycle by kickstarter should be possible with minimal effort.

6. ***Absorb forces:*** Forces due to pressure increase and combustion in the combustion chamber are absorbed from the cylinder head.

7. ***Take/Position elements:*** The cylinder head takes necessary mounting parts and is also responsible for their positioning.

8. ***Dense components:*** Water circulation and oil circuit must be separated and no liquid should escape. This means that this function also includes the enclosure towards the outside.

9. ***Satisfy styling demands:*** The cylinder head, the cylinder head cover, the cylinder and the crankcase are well styled, so that customers prefer to buy the new motorcycle.

4.5.2 Function Cost Matrix

Following the naming of the functions and the creation of the function tree, one function cost matrix for the YZF125 and one function cost matrix for the XY150 cylinder head assembly are created. By means of the function cost matrix, it is possible to split the part costs to the various functions. The cost of the functional carrier is allocated to the previously defined functions, which results in one part of the function cost. Once the cost of all function carriers is divided among the functions, the cross sum of each function is calculated. This gives the necessary cost to implement the respective function in the two different cylinder head assemblies.

The investigation area of the YZF125 cylinder head assembly consists of 36 function carriers, while the XY150 cylinder head assembly consists of 39 function carriers. The number of considered functions in the function cost matrix is 22 functions for both cylinder head assemblies. This results in a 36x22 function cost matrix for the YZF125 cylinder head assembly and a 39x22 matrix for the XY150. A spreadsheet program is used to perform the calculation because changes can be done very quickly. In addition, data sets are automatically transferred to other tab sheets and sorting operations can be automated.

Table 13 shows the calculation of the total cost for all functions of the YZF125 and the XY150 cylinder head assembly. The complete matrices for both the YZF125 and the XY150 cylinder head assembly are illustrated in Appendix B. The term "checksum" controls how much percent of the respective functional carrier is allocated to the functions. In the completely filled function cost matrices, “checksum” always requires a value of 100 percent, otherwise the cost of the concerned function carrier is either incompletely, (<100 percent) or overly (>100 percent) allocated to the functions.

In the column, "Function Cost (EUR)", the sum of the function cost is calculated. Again, the checksum is formed at the end of this line. This must coincide with the total cost of the function carrier.

In the column, "Function Cost (%)", the percentage proportion of the function cost to the total cost is calculated automatically. Also here, at the end of the line, a checksum is formed, where the value must equal 100 percent in the completely filled matrices. Otherwise, at least the cost of one function carrier is allocated incompletely (<100 percent) to the functions.

Both function cost matrices (see Appendix B) were first prepared in individual work and in groups of two, and finally approved by the project leader. The following sections describe the most valuable function carriers in detail and how the allocation of the cost of a function carrier to the functions was carried out. Also, the different considerations between equivalent parts of the YZF125 and the XY150 cylinder head assemblies are explained and compared to each other.

Function Tree				YZF125			XY150		
Main function	1. Auxiliary function	2. Auxiliary function	3. Auxiliary function	Function Cost [EUR]	Function Cost [%]	Ranking	Function Cost [EUR]	Function Cost [%]	Ranking
1 Exchange charge	1.1 Supply fresh gas	1.1.1 Pass fresh gas		€ 4.86	4.05%	11	€ 5.52	3.70%	10
		1.1.2 Control fresh gas supply	1.1.2.1 Open combustion chamber	€ 1.03	0.86%	19	€ 1.03	0.69%	20
			1.1.2.2 Close combustion chamber	€ 1.71	1.43%	15	€ 1.71	1.15%	16
	1.2 Discharge exhaust gas	1.2.1 Pass exhaust gas		€ 4.86	4.05%	11	€ 5.52	3.70%	10
		1.2.2 Control exhaust gas discharge	1.2.2.1 Open combustion chamber	€ 0.96	0.80%	20	€ 0.96	0.64%	21
			1.2.2.2 Close combustion chamber	€ 1.64	1.37%	16	€ 1.64	1.10%	17
2 Control combustion process	2.1 Initiate combustion			€ 5.70	4.74%	8	€ 5.70	3.82%	9
	2.2 Form combustion chamber			€ 1.29	1.07%	17	€ 1.46	0.98%	18
	2.3 Position valves			€ 20.48	17.04%	2	€ 28.15	18.89%	2
	2.4 Position spark plug			€ 2.31	1.92%	13	€ 2.64	1.77%	13
3 Control thermal balance	3.1 Transfer heat			€ 0.77	0.64%	21	€ 0.88	0.59%	22
	3.2 Pass cooling medium			€ 8.47	7.05%	5	€ 9.68	6.49%	4
	3.3 Measure temperature			€ 1.84	1.53%	14	€ 1.84	1.23%	14
	3.4 Control flow rate			€ 9.00	7.49%	3	€ 9.00	6.04%	5
4 Ensure lifespan	4.1 Withstand corrosion			€ 1.16	0.96%	18	€ 1.32	0.89%	19
	4.2 Minimize wear			€ 6.39	5.32%	6	€ 8.03	5.39%	6
5 Offer comfort	5.1 Meet maintenance requirements			€ 5.40	4.49%	9	€ 6.40	4.29%	8
	5.2 Facilitate starting process			€ 5.00	4.16%	10	€ 5.00	3.35%	12
6 Absorb forces				€ 5.84	4.86%	7	€ 6.53	4.38%	7
7 Take elements				€ 22.71	18.89%	1	€ 33.43	22.43%	1
8 Dense components				€ 8.62	7.17%	4	€ 10.77	7.23%	3
9 Satisfy styling demands				€ 0.15	0.12%	22	€ 1.83	1.23%	15
			TOTAL	€ 120.21	100%		€ 149.05	100%	

Table 13: Function Costs for YZF125 and XY150 Cylinder Head Assembly[184]

[184] Own illustration

Cylinder Head

The cylinder head itself is the most valuable and complex component of the complete engine. The production of the cylinder head is different. While the YZF125 cylinder head is a pure sand casting, the XY150 cylinder head is manufactured in a combination of sand casting (cores) and permanent mold casting (outer shape). Fig. 24 shows the XY150 cylinder head with a view on the bottom side.

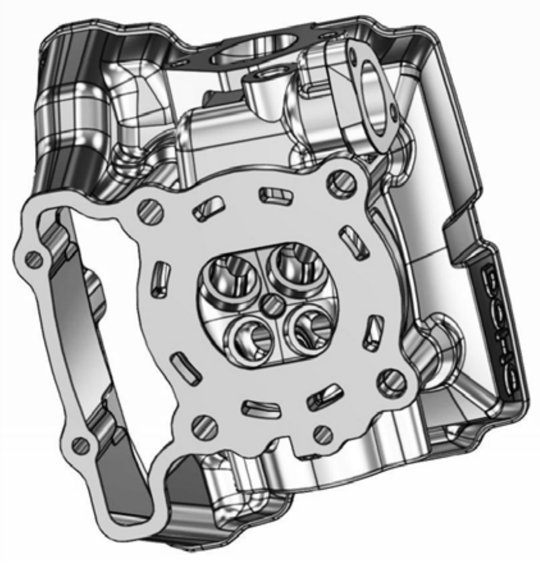

Fig. 24: Cylinder Head (XY150) - Bottom Side[185]

Fig. 25 shows the XY150 cylinder head from a different perspective.

Fig. 25: Cylinder Head (XY150) - Upper Side[186]

[185] Own illustration
[186] Own illustration

The main reason why sand cores have to be used is because the inlet and outlet channels cannot be removed in one direction from the mould. This is the difference to the outer contour, which can be removed from the mold. Also, the manufacturing of the water jacket channel requires sand cores. These cores are very complex and filigree. Compared to the inlet and outlet channels, very fine contours and thin walls are required for the water jacket to adequately remove heat from the combustion chamber. The percentage distribution of cost for the water jacket is therefore assessed with approximately the same proportion as the inlet and outlet channels together. The passing of the cooling medium also includes the connection flow channel with the thermostat. That results in an enlarged outline of the cylinder head contour, which occupies a small portion of the cylinder head casting.

The shape of the combustion chamber is easy to manufacture because this is an outer contour. The shape is integrated in the mould. Because the mold is CNC made and that means that it makes no difference what shape the combustion chamber is. Whether squares or round contours are milled in the CNC machining of the mould, makes no difference to the cost. From the functional side, the shape of the combustion chamber plays a significant role since the contour has a direct influence on the combustion process in the combustion chamber.

Two machining steps are required for the positioning of the spark plug. Firstly, the bearing surface for the spark plug and the core hole for the thread are pre-drilled with a stepped cutter. In a second step, the thread is cut. While the position of the spark plug is vertical in the XY150, the spark plug is placed in an inclined position in the YZF125.

Heat transfer is a physical process, which occurs between objects with different temperatures. Note, however, that the wall thickness between water jacket and combustion chamber is evenly thin. Thereby, a uniform expansion of the material is ensured.

By selecting the material, which is in the case of both the YZF125 and the XY150 cylinder head aluminum – aluminum only corrodes to a certain extent in the salt water. Using operating supplies (oil, water) ensures that the cylinder head withstands corrosion. Also, for the XY150 cylinder head, a drain hole for condensation water that can form in the spark plug hole in the middle of the cylinder head is required. This is needed because the spark plug position in the XY150 is vertical. The spark plug of the YZF125 has an inclined position on the side of the cylinder head and so this kind of a bore is not needed.

The coating is purely so that styling meets customer requirements. The YZF125 is not painted and has no such claims. In contrast, the styling plays a significant role for the XY150 cylinder head and therefore must be considered.

Basically, the cylinder head is the central element of the cylinder head assembly and absorbs all forces (gas pressure, forces of the valve train). This is the basic function of the cylinder head. However, in terms of cost, the satisfactions of the function absorb forces is moderately low because the wall thickness is primarily designed for the minimum wall thickness for castings. The strength requirements are defined by the wall thickness. Ribs are only for reinforcement in a particular direction. If no forces would act on the component, the shape would generally stay the same. Only the roof of the combustion chamber could be made thinner. This would lead to a simplification of the water jacket.

In the YZF125, the oil is transported through a cylinder head stud bolt hole and another bore to the inner bore of the camshaft. Through a splash bore, at the cam of the camshaft, the oil is distrubuted to the moving elements in the cylinder head assembly to minimize the wear. Similary, in the XY150, the oil is transported via the stud boltholes and camshaaft carrier center sleeves to the inner bore of the camshaft. Also here, a splash bore at the camshaft distributes the oil to the moving parts in the cylinder head assembly. Additionally, from a functional point of view, the oil circulation contributes to the removal of the heat. The cost to bring the oil to the necessary places is relatively expensive for the YZF125 because the cylinder head has an additional inlet hole. First the core hole must be drilled and then the thread must be cut. To realize the oil supply in the XY150 cylinder head assembly the stud boltholes are also used as inlet. Additionally, large center sleeves are required because the diameter of the center sleeves must be larger than the stud bolt nut. Also, precise tolerances are necesseray to fulfill the centering and sealing function. Furthermore, the camshaft center sleeves have an additional length of 20mm, to bridge the distance between stud boltholes and camshaft carrier. If the oil supply was realized in a differernt way (e.g. additional bore holes), the center sleeves are only used for positioning the camshaft carriers. Thus, the center sleeves would be standard parts and much smaller.

The transfer of oil to the moving parts does not matter a lot in terms of cost because the oil uses the existing stud bolt holes to rise into the cylinder head assembly. Therefore, only small grooves need to be manufactured.

To meet the maintenance requirements, a simple mounting and dismounting is necessary. General accessibility of tools to relevant places must be ensured. The setting screws for adjusting the valve clearance must be especially easily accessible.

The new design of the XY150 cylinder head assembly includes an additional component - the camshaft carrier. With the camshaft carrier, a common problem in the design of a cylinder head - that the stud bolts to fix the cylinder head collide with the bearings of the camshafts - is avoided. After the cylinder head is mounted to the crankcase, the camshaft carrier is attached to the cylinder head. The camshaft carrier contains the previously mounted camshafts. Therefore, the camshaft carrier can obscure the stud bolt nuts because the cylinder head is already fixed.

The cylinder head positions several components like bolts, screws, valve guides, thermostat, coolant sensor, center sleeves, exhaust and intake manifold. Therefore, some machining steps are necessary to provide the required holding fixtures. Additionally, YZF125 cylinder head carries the water pump, for which the large flange is required. In addition, the position of the bearings for the camshaft must be considered.

The sealing function is basically attributed to the seal, although two components are always involved in sealing. The function dense component also includes the enclosure towards the outside and therefore the outer contour of the cylinder head is the seal of the cylinder head assembly to the outside.

The bore for the secondary air supply of the XY150 is designed in a different way compared to the YZF125. While the YZF125 cylinder head assembly supplies the air via the cylinder head cover and a hole in the cylinder head into the exhaust port, the air in the XY150 cylinder is passed via a short bore in the cylinder head into the exhaust channel. A cost difference between the two concepts is not noticable, since a respective bore must be made in both cylinder heads. Only the length is different (longer bore in the YZF125 cylinder head).

Cylinder Head Gasket

The overall contour of the cylinder head gasket is punched at once. Also included in this process, are the holes for the coolant water, the oil and the cut for the chain chamber. To withstand corrosion, the seals are made of a material, which is suitable for the usage of the gasket and which is resistant to the oil and the cooling water.

Cylinder Head Cover

The XY150 cylinder head cover is larger compared to YZF125. Also, styling plays a significant role in the design of the XY150 cylinder head cover, in contrast to the YZF125. Additionally, the YZF125 cylinder head cover contains the holding fixture for the secondary air supply and a supplementary bore, which is closed again subsequent to its manufacturing. In comparison, the secondary air supply for the

XY150 is located on the cylinder and connected with the exhaust channel by a short bore in the cylinder head.

Bores and bearing surfaces for screws to fix the cylinder head covers on the cylinder head must be machined. The YZF125 cylinder head cover is fixed with five screws (five bores) and the XY150 is fixed with two screws and two washers (two bores). As the amount of bores has no effect on the processing directions, the distribution of costs for the YZF125 and the XY150 cylinder head cover are performed in the same way.

The main function of the cylinder head cover is attributed to the enclosure of the cylinder head assembly towards the outside.

In the design of the YZF125 cylinder head cover, no attention was given to styling demands. For the XY150, styling plays an important role to attract attention of customers. This is also evident in the DOHC lettering on the outer contour and the coating of the cylinder head cover.

Intake Valve Seat and Exhaust Valve Seat

The intake and exhaust valve seats of the YZF125 and the XY150 are not identical but basically there is no difference.

The valve seats are pressed into their provided position in the cylinder head. After pressing the valve guides into the cylinder head, all four transitions between the inlet and respectively outlet channel and the seat rings are post-processed with a stepped cutter. In the same machining step, the valve guides are also grounded so that the concentricity of the valve guides and the intake and exhaust valves is guaranteed. This is necessary to ensure optimum movement of the valves.

The task of the intake valve seats is to guide fresh gas from the inlet channel into the combustion chamber. The exhaust valve seats pass the exhaust gas into the exhaust channel. The seat rings have a special shape in order to ensure good flow conditions. The shape of the inlet valve seats has several edges and is conically designed so that a specific inflow direction can be obtained. In contrast, the shape of the exhaust valve seats is made circular, so that the exhaust gas can flow into the outlet channel like through a funnel.

The seat rings provide the bedstop for the valves. Therby, the valve seats and valves seal the combustion chamber. To minimize wear of the valve seats, these parts must be hardened. The durability against mechanical stress of the valves (pressure, speed of the bedstops) has to be ensured. The seat rings provide a specified seat to the valves. The difference in size of the valves in YZF125 and XY150 is minimal. In the

XY150, the exhaust valves are one millimeter greater in diameter and the inlet valves are one millimeter smaller compared to the YZF125 valves. For a sealing function, two parts are involved. In this case, the sealing function is attributed only to the valve seat rings.

Intake Valve and Exhaust Valve

The main function of the valves is to open and close the combustion chamber. Also, the valves build a part of the combustion chamber. But the cost for the function form combustion chamber is just a small proportion of the total valve cost because the shape of the underside of the valve is forged either flat or only with a slight curvature. Furthermore, a groove is cut into the valves for taking the valve springs and collets. The valve surface and the groove are hardened, so that the wear is minimized. Likewise, the scraping edge on the valve stem, which is responsible for ensuring that deposits are sheared from the valve guide out, is hardened too. Fig. 26 shows the intake valve group including valve spring carriers, valve springs, valve stem seals, valve guides, intake valves and intake valve seats.

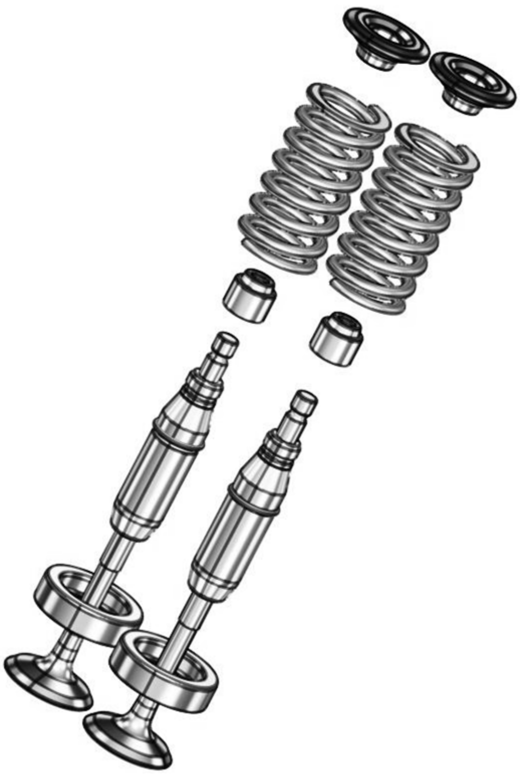

Fig. 26: Intake Valve Group (XY150)[187]

[187] Own illustration

Rocker Arm and Cam Follower

The YZF125 has an intake and an exhaust rocker arm. The XY150 has an intake and exhaust cam follower. Rocker arm and cam follower are castings made of steel. The main task of rocker arm and cam follower is the actuation and positioning of the valves in axial direction.

The sub-assembly of rocker arm and cam follower includes the adjusting screws, which are needed to adjust the valve clearance. Fig. 27 illustrates the XY150 cam follower with adjusting screws.

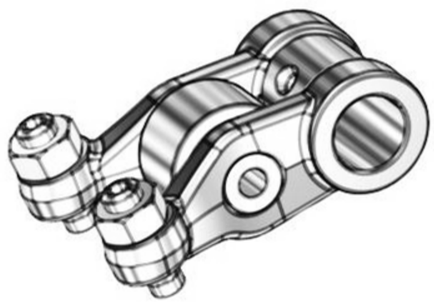

Fig. 27: Cam Follower with Adjusting Screws (XY150)[188]

The inertia forces play the major role in dimensioning rocker arm and cam follower. In comparison, the absorbance of the forces from the valve springs, which act on the rocker arm or cam follower, can be neglected.

Camshaft

The YZF125 cylinder head assembly has one camshaft with two cams. The XY150 cylinder head assembly has two camshafts, each with one cam. The camshaft is a cast steel part manufactured with many machinings (bearing seat, cam profile, etc.). The intake and exhaust camshaft of the XY150 are different, because the exhaust camshaft locates the decompressor system. Therefore the exhaust camshaft also meets the function take elements. The cost difference between intake and exhaust camshaft is about 20 percent. The main function of the camshafts is the actuation and movement of the valves via the rocker arm and cam follower. Furthermore, the camshafts support the minimize wear function because the oil bores in the camshafts transport the oil to the bearings. In addition, the oil is distributed within the cylinder head assembly via the splashbores (two bores located in the middle and directly on the cam). The intake camshaft of the XY150 can be seen in Fig. 28.

[188] Own illustration

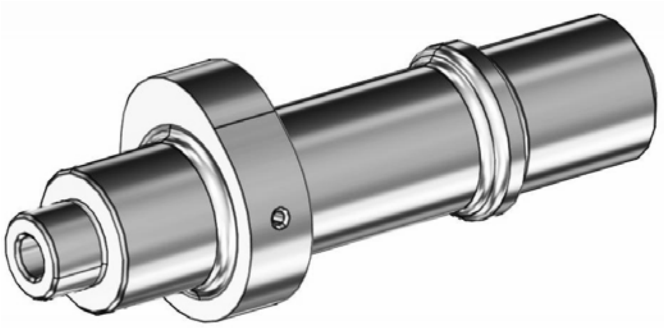

Fig. 28: Intake Camshaft (XY150)[189]

Camshaft Carrier

The camshaft carrier is a part, which exists only in the XY150 cylinder head assembly. The main task of the camshaft carrier is the bearing housing of the intake and exhaust camshaft and the cam followers. Furthermore, the camshaft carrier has to absorb the forces from the valve train. To fulfill the minimize wear function the camshaft carrier directs the oil, via bores, from the camshaft carrier center sleeves to the intake and exhaust camshaft. The idea behind the camshaft carrier is that the intake and exhaust camshaft are assembled to this component. This can be realized outside the cylinder head and then the whole subassembly is mounted to the cylinder head. Thereby, the mounting procedure of the cylinder head assembly is considerably simplified and maintenance is made easier. Fig. 29 illustrates the design of the camshaft carrier.

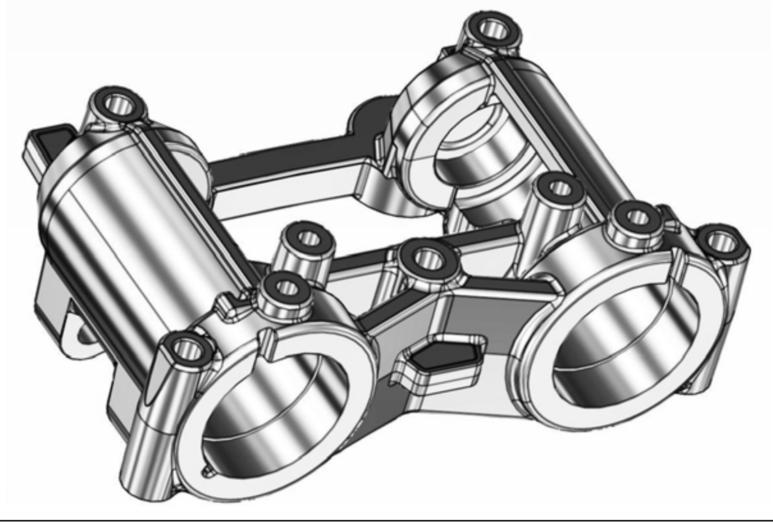

Fig. 29: Camshaft Carrier (XY150)[190]

[189] Own illustration
[190] Own illustration

Chain Guide

In addition to the upper guidance of the timing chain, the chain guide has the function of positioning the outside bearings of the intake and exhaust camshaft. The chain guide is made of a steel sheet that is punched and edged twice. Furthermore, a rubber kidney is stuck on the top. The counterpart in the YZF125 cylinder head assembly is the so-called locking plate, which is much smaller and does not contain a rubber kidney. Therefore there is a difference in cost of the two parts. Fig. 30 shows the upper chain guide for the XY150 cylinder head assembly.

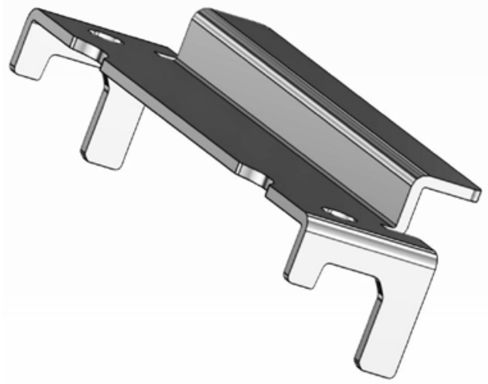

Fig. 30: Upper Chain Guide (XY150)[191]

ABC Analysis of Functions

After using the function cost matrices to allocate the component costs of the YZF125 and the XY150 to the functions, an ABC analysis with all functions is performed for both cylinder head assemblies. So, the functions are sorted according to their cost. The ABC analysis filters out the most valuable functions with the largest share of the total cost of the cylinder head assemblies. The graphical distribution of the function costs for the YZF125 (dotted line) and XY150 (solid line) are displayed in Fig. 31. It can be seen that the percentage proportion of the functions are almost the same for both cylinder head assemblies, when the functions are related to the respective total costs.

[191] Own illustration

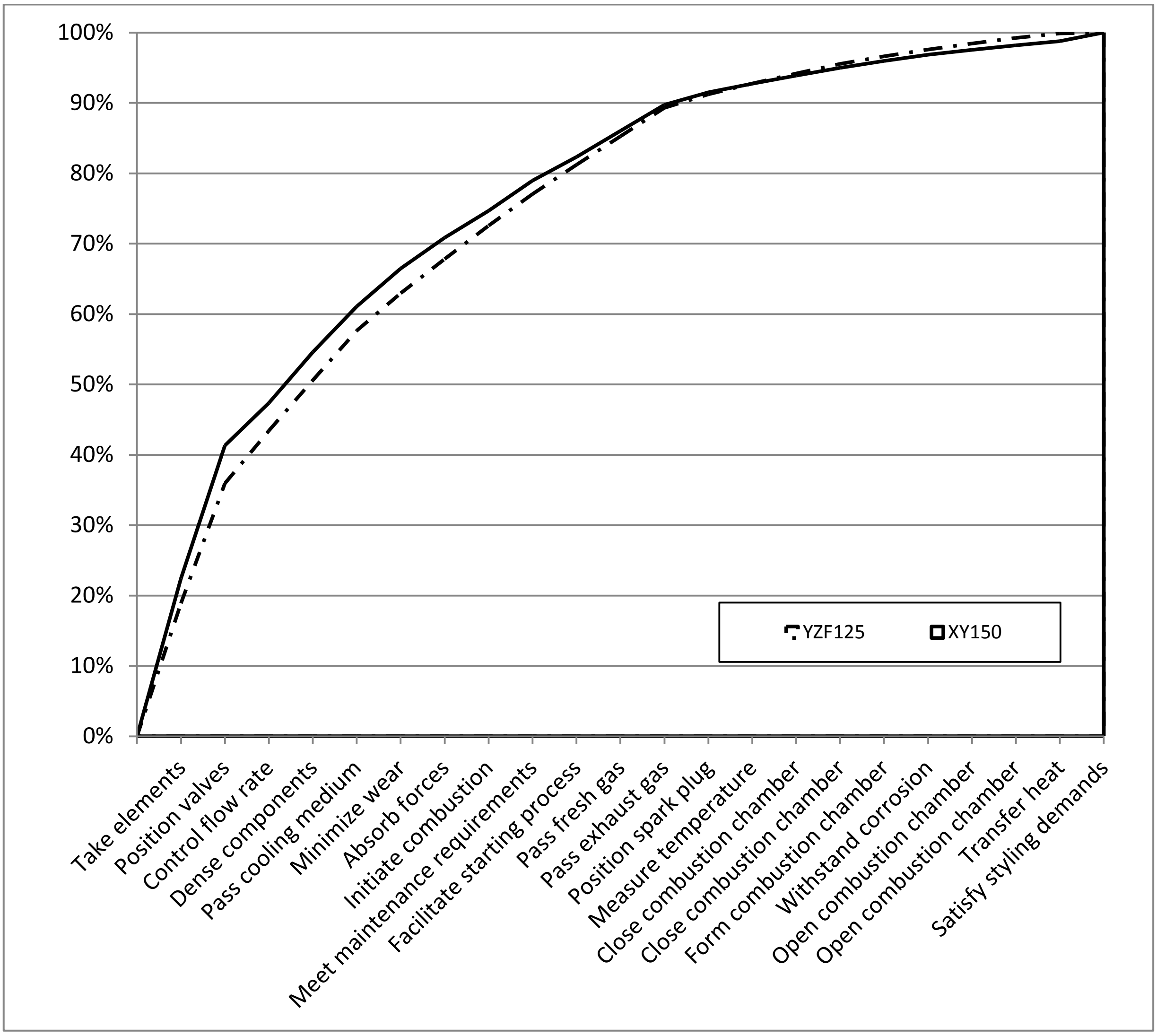

Fig. 31: ABC Analysis of Functions[192]

4.5.3 Degree of Functional Performance

After the function costs are identified and the cost driving functions are determined, each function is evaluated with respect to its degree of functional performance. Table 14 shows the evaluation of the degree of functional performance for the YZF125 cylinder head assembly. The table is sorted according to the cost of the functions in descending order. Following the tabular overview, it is described for each function how the assessment of the degree of functional performance was performed and what considerations have played a role in the evaluation process. Additionally, the required criteria for the repective functions are described in detail. The performance

[192] Own illustration

criteria are also used as reference for the evaluation of the degree of functional performance.

Ranking	No.	Function	Function Cost YZF125 [EUR]	Function Cost YZF125 [%]	Accumulated [%]	Degree of Functional Performance	Potential for Change [%]	Change of Cost [EUR]
1	7	Take elements	€ 22.71	18.89%	18.89%	50%	50%	€ 11.35
2	2.3	Position valves	€ 20.48	17.04%	35.93%	60%	40%	€ 8.19
3	3.4	Control flow rate	€ 9.00	7.49%	43.42%	100%	-	-
4	8	Dense components	€ 8.62	7.17%	50.59%	100%	-	-
5	3.2	Pass cooling medium	€ 8.47	7.05%	57.64%	60%	40%	€ 3.39
6	4.2	Minimize wear	€ 6.39	5.32%	62.95%	100%	-	-
7	6	Absorb forces	€ 5.84	4.86%	67.81%	120%	-20%	-€ 1.17
8	2.1	Initiate combustion	€ 5.70	4.74%	72.55%	100%	-	-
9	5.1	Meet maintenance requirements	€ 5.40	4.49%	77.05%	90%	10%	€ 0.54
10	5.2	Facilitate starting process	€ 5.00	4.16%	81.20%	100%	-	-
11	1.1.1	Pass fresh gas	€ 4.86	4.05%	85.25%	70%	30%	€ 1.46
12	1.2.1	Pass exhaust gas	€ 4.86	4.05%	89.30%	80%	20%	€ 0.97
13	2.4	Position spark plug	€ 2.31	1.92%	91.22%	100%	-	-
14	3.3	Measure temperature	€ 1.84	1.53%	92.75%	100%	-	-
15	1.1.2.2	Close combustion chamber	€ 1.71	1.43%	94.18%	100%	-	-
16	1.2.2.2	Close combustion chamber	€ 1.64	1.37%	95.54%	100%	-	-
17	2.2	Form combustion chamber	€ 1.29	1.07%	96.62%	40%	60%	€ 0.78
18	4.1	Withstand corrosion	€ 1.16	0.96%	97.58%	100%	-	-
19	1.1.2.1	Open combustion chamber	€ 1.03	0.86%	98.44%	100%	-	-
20	1.2.2.1	Open combustion chamber	€ 0.96	0.80%	99.23%	100%	-	-
21	3.1	Transfer heat	€ 0.77	0.64%	99.88%	100%	-	-
22	9	Satisfy styling demands	€ 0.15	0.12%	100.00%	10%	90%	€ 0.14
		TOTAL	**€ 120.21**	**100.00%**				**€ 25.65**

Table 14: Evaluation of the Degree of Functional Performance for YZF125[193]

The following sections describe how the evaluation of the degree of functional performance for each function was carried out.

Take Elements

The cylinder head assembly needs to take and position all necessary components. This requirement must be met. In the assessment it is also considered how well or poorly the solution of the holding fixtures is realized (eg. securing of bearings) and whether sufficient safety is assured. Due to the requirements and the decision to

193 Own illustration

integrate the DOHC technology within the new cylinder head assembly, the YZF125 engine is rated with 50 percent because the valve train consists of only one camshaft. The XY150 is rated with 100 percent because the design is exactly adapted to the given requirements. Furthermore, it is considered that all holding fixtures are implemented as easily as posssible.

Position Valves

For the XY150, the speed of 12,000rpm has to be attained. But the YZF125, with its SOHC design, only reaches a maximum of 10,500rpm. That was also a reason for the decision to use two overhead camshafts as valve train, because with the DOHC technology it is possible to achieve higher engine speeds. The reason is that the weight of the cam followers can be reduced and therefore the moment of inertia is lower. In addition, it is not necessary to use stronger valve springs because stronger springs would lead to increased friction and subsequently, to an increased fuel consumption rate.

The valve lift has to reach 8mm according to the requirements. The valve lift of the YZF125 is only 7mm. However, the XY150 achieves exactly the requested 8mm.

Position Spark plug

The positioning of the spark plug in the YZF125 cylinder head assembly is not very well chosen because it is placed inclined. For maintenance reasons, the inclined position of the spark plug may be the better one but this means that the water jacket cannot be designed balanced and symmetrically, which is much more important. The requirement for a good combustion process is that the spark initiates the combustion centrally in the combustion chamber, in the middle between the valves. That is achieved by the YZF125 and the XY150 concept.

Pass Cooling Medium

The requirements for a balanced and sufficient cooling must be met. On the test bench, it turned out that the engine operates close to the knock limit and the heat transfer is not sufficiently satisfied. Therefore, the YZF125 does not correspond to the specified requirements. As mentioned before, the inclinded position of the spark plug is the reason why the water jacket cannot be formed as balanced and symmetrical. Thus, sufficient cooling of the YZF125 cannot be achieved. During the design of the XY150, it was very important that the water jacket is really symmetrical and ensures sufficient cooling.

Form Combustion Chamber

Due to the SOHC design in the YZF125, the valve angle to the vertical is relatively large compared to the valve angle in the XY150. Therefore, the combustion chamber roof has to be deeper in the YZF125. But a flat shape of the combustion chamber roof is necessary to realize a modern combustion process, with good performance and good emission values. This requirement corresponds to the design of the XY150 due to the choice of the DOHC concept.

Meet Maintenance Requirements

It is a requirement to use screws for adjusting the valve clearance. The reason is that the adjustment of the valve clearance can only be done by using only a standard wrench and pliers, without additional special tools. Also, it is not necessary to dismount the cam follower for the adjustment. In order to gain access to the adjusting screws, the five screws of the YZF125 cylinder head cover need to be opend and the hose for the secondary air supply must be removed. For the XY150, that process is simpler because only two screws must be resolved as the secondary air supply is not positioned at the cylinder head cover but at the cylinder. From a different point of view, the XY150 cylinder head is much bigger and higher and therefore probably not as easily removed as the YZF125's small cylinder head cover.

Dense Components

All gaskets and outer parts fullfil this function. On the one hand, to keep the oil circuit and the water flow separate and on the other hand, to prevent leakage of oil and water from the cylinder head assembly. Actually, the XY150 overachieves the dense components function because it satisfies an additional function, namely 'dampen vibrations and position parts'. The design of the cylinder head cover gasket prevents metal-to-metal contact and thus reduces the transmission of vibration. In addition, the gasket positions the cylinder head cover (see Fig. 32). The cylinder head cover gasket in the YZF125 is realized very simply with an o-ring seal. Thus, metallic contact between cylinder head and cylinder head cover transmits vibration of the engine to the outside.

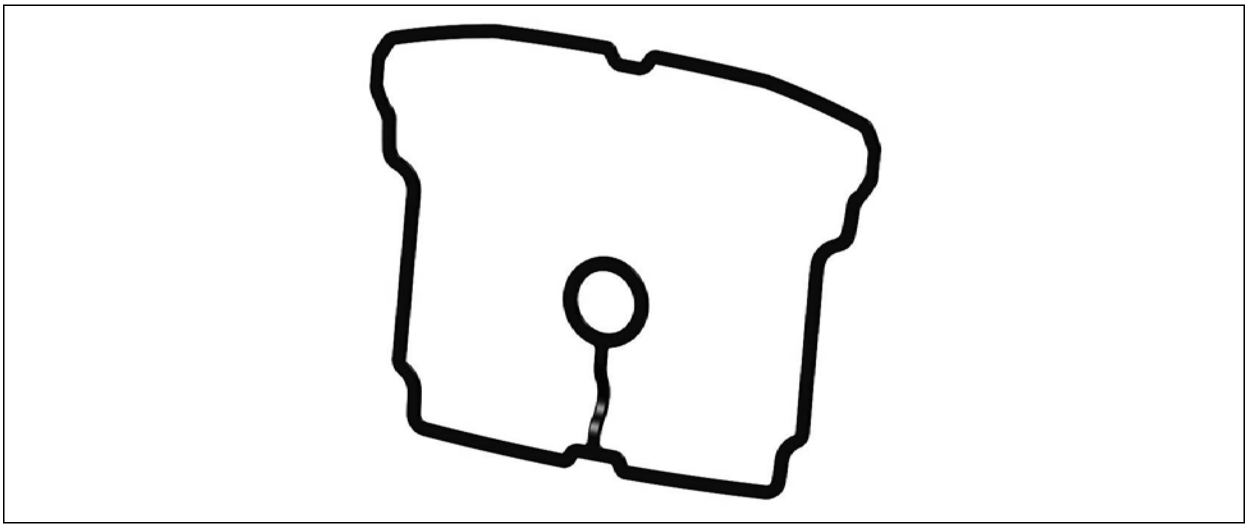

Fig. 32: Cylinder Head Cover Gasket (XY150)[194]

Minimize Wear

The YZF125 leads the oil through a stud bolthole and a supply bore to the camshaft. The XY150 also passes the oil over the studs and through the camshaft carrier center sleeves and via the camshaft carrier into the camshaft. By the usage of boltholes for leading the oil, additional bores or oil supply can be saved.

Absorb Forces

The wall thickness of the XY150 cylinder head is 4mm. In comparison, the wall thickness of the YZF125 is persistently a minimum of 6 mm. It is worth noting that the YZF125 cylinder head also includes the suspension point of the engine and so the cylinder head transmits the load to the frame. By calculation, an optimization is possible but this would have to be tested and verified on a dynamometer. Therfore, the absorb forces function for the YZF125 is assessed with 120 percent, which means that the function is slightly overfulfilled.

Pass Fresh Gas and Pass Exhaust Gas

Generally, over-achieving of these functions is not possible. However, the XY150 has optimized channel geometry and maintains better flow conditions compared to the YZF125. This results from the fact that the YZF125 water jacket is not symmetric and the valve angle is steeper to the vertical.

[194] Own illustration

Withstand Corrosion

The XY150 cylinder head requires additional effort for fulfilling this function. Because of the central and vertical position of the spark plug, a bore is necessary to allow the condensation drainage. Both, the YZF125 and the XY150 fulfill the withstand corrosion function at 100 percent but the function cost is different. This is evident in the two function cost matrices (see Appendix A and Appendix B).

Satisfy Styling Demands

The YZF125 does absolutely not meet the given sytling requirements. During the design of the XY150, value is placed on the styling, to attract the attention of the customers for the new XY150 motorcycle engine. Therefore, a robust, sporty and modern styling and a noble coating are considered for the outer shape. The DOHC lettering on the cylinder head cover especially highlights the satisfy styling demands function, to strengthen the trust of customers for the XY150. This is because as already mentioned, the DOHC lettering demonstrates that modern technology is integrated within the XY150 cylinder head assembly.

Remaining Functions

Components like thermostat, spark plug and temperature sensor are identical for the YZF and the XY150. Also the control flow rate, open and close combustion chamber and transfer heat functions are realized equally for both cylinder head assemblies. Therefore, these functions are not described separately. Savings can be made by the choice of cheaper suppliers, if the products meet the same requirements as the proposed components.

Comparison of YZF125 and XY150 Cylinder Head Assembly

It must be mentioned, that the comparison of the YZF125 and XY150 is quite difficult because the cylinder head assemblies are two completely different concepts (SOHC vs. DOHC). Anyway, in Table 14 the YZF125 function costs and the XY150 cylinder head assembly can be seen next to each other. The YZF125 is cheaper by 24 percent but as already mentioned, the YZF125 cylinder head assembly does not meet the given requirements.

No.	Function	Function Cost YZF125	Function Cost XY150	Difference [EUR]	Difference [%]
1.1.1	Pass fresh gas	€ 4.86	€ 5.52	€ 0.66	13.53%
1.1.2.1	Open combustion chamber	€ 1.03	€ 1.03	-	-
1.1.2.2	Close combustion chamber	€ 1.71	€ 1.71	-	-
1.2.1	Pass exhaust gas	€ 4.86	€ 5.52	€ 0.66	13.53%
1.2.2.1	Open combustion chamber	€ 0.96	€ 0.96	-	-
1.2.2.2	Close combustion chamber	€ 1.64	€ 1.64	-	-
2.1	Initiate combustion	€ 5.70	€ 5.70	-	-
2.2	Form combustion chamber	€ 1.29	€ 1.46	€ 0.17	12.77%
2.3	Position valves	€ 20.48	€ 28.15	€ 7.67	37.47%
2.4	Position spark plug	€ 2.31	€ 2.64	€ 0.33	14.29%
3.1	Transfer heat	€ 0.77	€ 0.88	€ 0.11	14.29%
3.2	Pass cooling medium	€ 8.47	€ 9.68	€ 1.21	14.29%
3.3	Measure temperature	€ 1.84	€ 1.84	-	-
3.4	Control flow rate	€ 9.00	€ 9.00	-	-
4.1	Withstand corrosion	€ 1.16	€ 1.32	€ 0.17	14.29%
4.2	Minimize wear	€ 6.39	€ 8.03	€ 1.64	25.69%
5.1	Meet maintenance requirements	€ 5.40	€ 6.40	€ 1.00	18.52%
5.2	Facilitate starting process	€ 5.00	€ 5.00	-	-
6	Absorb forces	€ 5.84	€ 6.53	€ 0.69	11.73%
7	Take elements	€ 22.71	€ 33.43	€ 10.72	47.19%
8	Dense components	€ 8.62	€ 10.77	€ 2.15	24.92%
9	Satisy styling demands	€ 0.15	€ 1.83	€ 1.68	1120.00%
	TOTAL	**€ 120.21**	**€ 149.05**	**€ 28.84**	**23.99%**

Table 15: Comparison of Function Cost[195]

Detailed Objectives

Table 16 shows the target price for the newly designed XY150 cylinder head assembly after the assessment of the degree of functional performance of the benchmark cylinder head assembly. The cost of 145.85 EUR is set as a target price for the XY150. The estimated overall cost of the XY150 cylinder head assembly is 149.05 EUR. The differences is 3.19 EUR or 2.19 percent. There are two main reasons, why the XY150 does not reach the target cost:

- DOHC instead of SOHC
- Camshaft carrier as additional part

[195] Own illustration

The additional costs are, however, necessary in order to meet the requirements of the client. On the other hand, machining directions are saved for the manufacturing of the XY150 and also the maintainability is increased due to the additional camshaft carrier.

Cost of YZF125 Cylinder Head Assembly [EUR]	**€ 120.21**
Change of Cost [EUR]	**€ 25.65**
Target Cost of XY150 Cylinder Head Assembly [EUR]	**€ 145.85**
Estimated Cost of XY150 Cylinder Head Assembly [EUR]	**€ 149.05**
Difference [EUR]	**€ 3.19**
Difference [%]	**2.19%**

Table 16: Difference between Target Cost and Estimated Cost of XY150 Cylinder Head Assembly[196]

4.6 Work Step 5 “Gathering and Creation of Solution Ideas”

In this VA project, work step 5 focuses on the collection of existing ideas. In a project team meeting the integrated solution ideas were collectied and summarized. The ideas were reviewed, advantages and disadvantages discussed and possible alternatives described.

4.7 Work Step 6 “Evaluation of Solution Ideas”

The following list summarizes the ideas that have been selected for implementation in the cylinder head assembly of the XY150:

- ***Reduction of machining directions:*** In the design of the XY150 cylinder head assembly the reduction of as many machining directions as possible is attempted, which leads to cost savings.

- ***Vertical and horizontal machining directions:*** All machining directions are horizontal or vertical. The only exception is the machining of the valve seats, as they have to be inclined.

- ***Easy mounting:*** Due to the design of an additional part - the so-called camshaft carrier - it is possible to pre-mount the camshafts and fix the camshaft carrier as one part on the cylinder head.

[196] Own illustration

- ***Camshaft carrier:*** From the camshaft carrier, a reduction of machining directions and a simplification of mounting is expected. Also, the camshaft bearing takes place independently from the cylinder head. In manufacturing, shifting and positioning operations can be saved. This design should facilitate the entire machining of both the cylinder head and camshaft carrier.

- ***Roller bearing:*** The usage of roller bearings results in reduced inner friction compared to plain bearings. Moreover, roller bearings are more robust and also work too, if only little oil is left in the engine. Above all, the emergency running characteristics play an important role in the requirements because it cannot be assumed that everyone keeps the marked oil change intervals. Moreover, it often happens that people often do not refill professional engine oil due to cost reasons and often just use simple cooking oil instead. That is also the reason why the design of the engine has to be very robust. In comparison, a plain bearing gets destroyed within a short time without proper oil supply. Therefore, not only the bearing of the cam follower but also the bearing of the camshaft itself is realized using roller bearings (see Fig. 33), although the modern design for engines uses plain bearings as a standard.

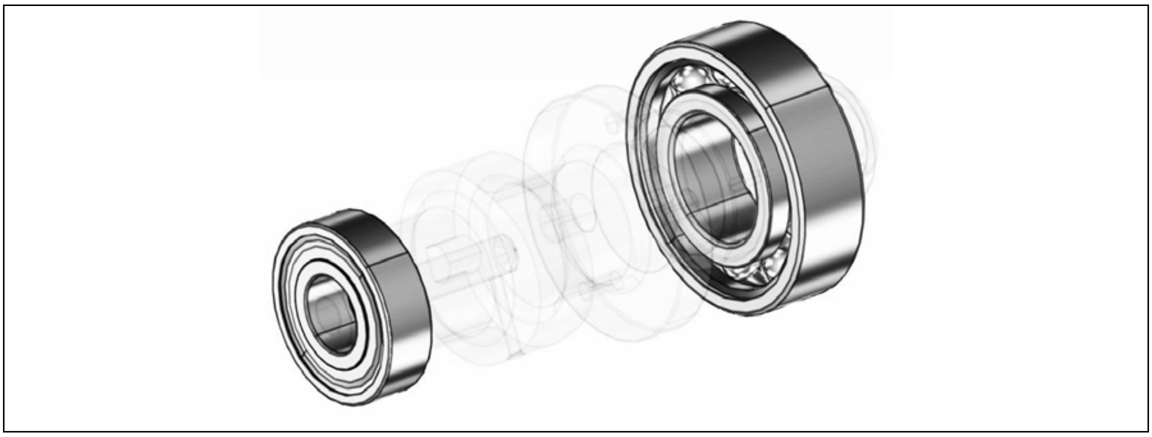

Fig. 33: Camshaft Roller Bearings (XY150)[197]

- ***Reduction of moment of inertia:*** To reduce moving masses, it is also possible to use shims instead of the adjustment screws and nuts. This ability to adjust the valve clearance is actually the modern technology that is used. But the customer has decided to go for the method of adjustment screws and nuts due to maintenance reasons.

[197] Own illustration

- ***Omitting oil drainage hole:*** By omitting the oil drainage hole, one machining step is saved. The cylinder head is filled with material at certain spots to ensure that the oil is passed to the chain chamber and can flow back into the oil bath. But this solution concept only works if the engine is placed with a 45-degree inclination in the motorcycle. Actually, this was implemented due to requests of the customer.

- ***Optimized channel geometry:*** The geometry of the inlet channel plays an important role for the amount of fresh gas introduced into the combustion chamber. In the YZF125 cylinder head, the cross-sections of the channels are relatively small and the channel curvatures are large. The inlet channel enters into the cylinder at almost 90 degrees. In the XY150, the channel geometry comes steeply from the top into the cylinder and therefore hardly has a curvature, which means the channel is designed as straightforward as possible. This results in less turbulent and more controlled fresh gas flow and therefore the filling of the combustion chamber with fresh gas is improved, which leads to an increase in performance and efficiency. Simulations show that the geometry of the XY150 inlet channel achieves a reduced friction factor at the same displacement and speed in comparison to the YZF125. However, the results have to be confirmed by real testing.

- ***Enlargement of the valve diameter:*** The bore of the XY150 engine varies between 52mm (125cc), 56mm (150cc) and 62mm (176cc). The geometry of the cylinder head must be referenced to the minimum bore. Therefore, the valve diameter for the bore of 52mm should be realized as large as possible. The YZF125 also has a bore diameter of 52mm. For the XY150, a further enlargement of the valve diameter of 0.7mm can be achieved. The distance to the edge is reduced to an optimum level. The gas-dynamic resistance can be minimized via the valve size. The simulation and design for improved performance and efficiency, however, is done for the 150cc engine. The geometry of the outlet channel is not as crucial as of the inlet channel because the exhaust is discharged from the combustion chamber more easily by the gauge pressure after combustion. The expectation is that by the implementation of increased intake valve diameters and slightly reduced exhaust valve diameters, the exhaust removal is not decreased but the fresh gas supply is improved.

- ***Reducing valve angle*:** By reducing the valve angle, it is possible to realize a flatter combustion chamber roof, which leads to an improved combustion process in the combustion chamber. The smaller valve angle is achieved by the application of two overhead camshafts.

- ***Usage of cam followers:*** The XY150 uses cam followers for the actuation of the valves, while the YZF125 uses rocker arms. The difference in actuation between cam followers and rocker arms is shown in Fig. 34. At the same leverage and thus same transmission ratio, cam followers can save weight in comparison to rocker arms. Rocker arms always need the camshaft below and in contrast cam followers always need the camshaft above.

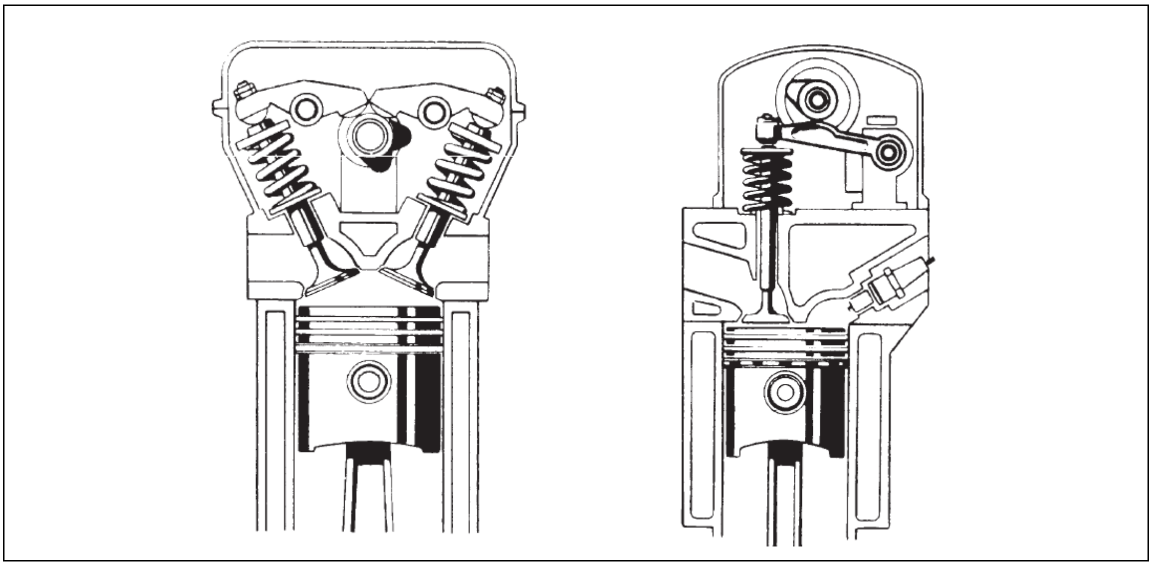

Fig. 34: Difference between Cam Follower and Rocker Arm[198]

The cam followers are optimized in terms of their moments of inertia by reducing weight. Characterized with the same spring stiffness, higher speeds can be driven or at the same speed valve springs with lower spring stiffness can be used. This results in lower friction and leads to a better engine efficiency.

[198] Böge (2011), p.L61

- ***Increased valve lift:*** The valve lift of the YZF125 reaches 7mm. In comparison, the XY150 provides a valve lift of 8mm in the design. But after the manufacturing of prototypes, it must be tested (on the test bench) whether 7mm would be enough to achieve the requirements and whether there is a great benefit of the enlarged valve lift or not. The negative effects of the valve lift increase are higher accelerations and inertia forces. Then the stiffness of the valve springs has to be increased, which leads to an increase in friction.

- ***Central spark plug position:*** The central spark plug position is beneficial because then the water jacket can be designed in a symmetric and balanced way.

- ***Symmetric and balanced water jacket:*** A balanced water jacket improves the transfer of heat away form the combustion chamber.

- ***Reduction of noise emission:*** Due to the use of a rubber seal instead of an o-ring seal, (YZF125) between cylinder head and cylinder head cover the vibration transmission is attenuated. The design is indeed associated with higher costs but it increases the driver comfort.

4.8 Work Step 7 “Development of Global Proposals”

This chapter summarizes the golbal concept for implementation in the cylinder head assembly of the XY150. The following sections present visual subassemblies and components of the cylinder head assembly and describe how the subassemblies and components are realized.

4.8.1 Valve Train Concept

Fig. 35 displays the valve train concept. In order to increase the effective flow area, the XY150 engine is equipped with two inlet and two outlet valves. The valve angle is minimized to get a compact, state of the art combustion chamber. Using the full potential of the ports, they have a straight geometry.

Fig. 35: Valve Train (XY150)[199]

4.8.2 Valve Actuation

Two overhead camshafts actuate the valves, which can be seen in Fig. 36. Each camshaft has one single cam operating a split type roller cam follower. With screws on the front end, it is possible to adjust the valve clearance.

Fig. 36: Valve Actuation (XY150)[200]

[199] FVT (2012d), p.95
[200] FVT (2012d), p.96

4.8.3 Cylinder Head

The cylinder head design (see Fig. 37) is done according to the requirements of the valve train, optimized thermodynamics and a state of the art optical appearance. In the picture, the cylinder, intake manifold, chain and chain guide can also be seen.

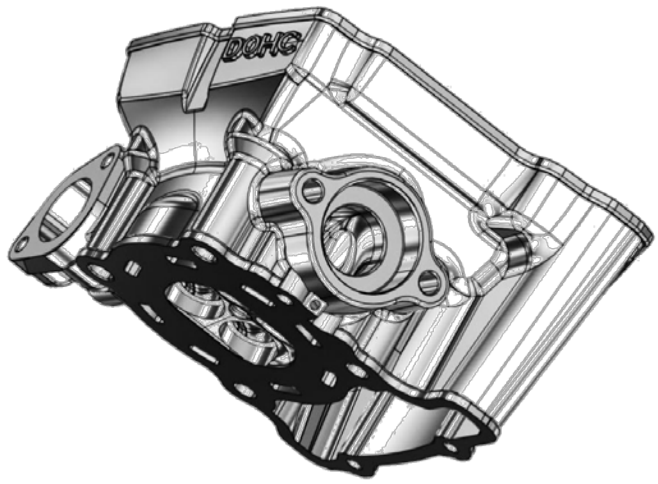

Fig. 37: Cylinder Head (XY150)[201]

4.8.4 Intake Port

For best possible gas exchange and charge motion, a straight intake port geometry is realized. The port is optimized by means of 3D-CFD calculation. Due to packaging reasons in the vehicle, the intake port is orientated to the front end.

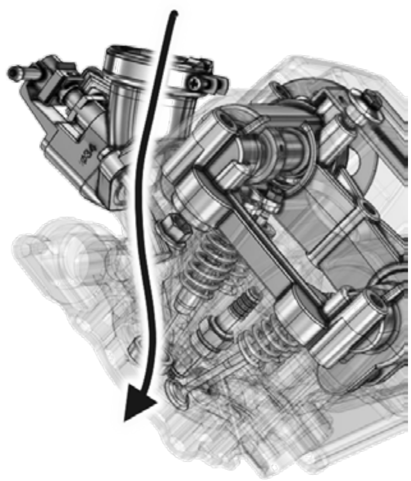

Fig. 38: Intake Port Orientation (XY150)[202]

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[201] FVT (2013), p.6
[202] FVT (2012d), p.102

4.8.5 Cylinder Head Cover

Fig. 39 shows the design of the cylinder head cover. The DOHC lettering on the cylinder head cover especially highlights that modern technology is integrated within the XY150 cylinder head assembly.

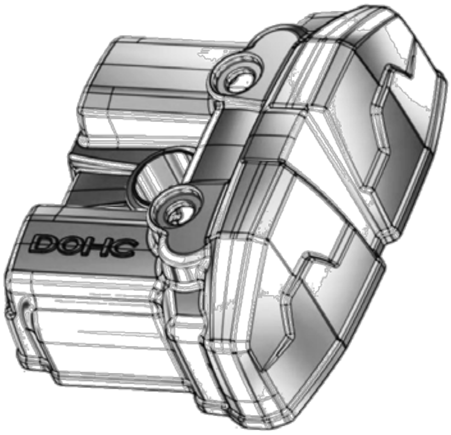

Fig. 39: Cylinder Head Cover (XY150)[203]

4.8.6 Combustion Chamber

In order to achieve an efficient and fast combustion, the valve angle is minimized for a flat combustion chamber shape. Due to the DOHC configuration, it is possible to locate the spark plug central in a vertical direction. This can be seen in Fig. 40. Within the limits of the bore diameter at 125cc (52mm), the valve is increased to a maximum. With this configuration, it is possible to tap the full potential of the inlet port geometry.

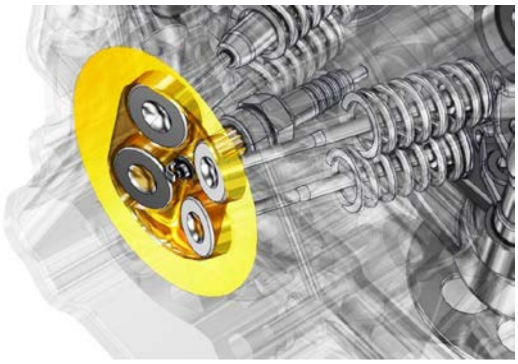

Fig. 40: Combustion Chamber (XY150)[204]

[203] FVT (2013), p.18
[204] FVT (2012d), p.103

4.8.7 Water Jacket

The water jacket (see Fig. 41) of the cylinder head, which is located around the combustion chamber, is designed in a split type way. Therefore, a symmetric flow of coolant can be maintained to achieve the best possible heat transfer.

Apart from the thermodynamic optimization, the manufacturing of sand cores for the casting process is taken into account.

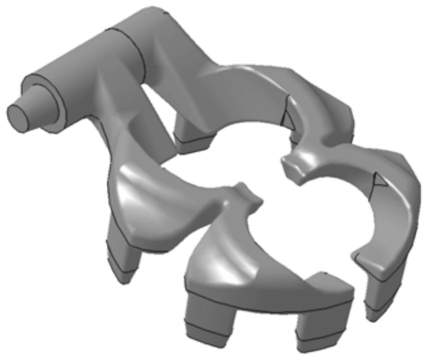

Fig. 41: Water Jacket (XY150)[205]

4.8.8 Valve Train Carrying System

Fig. 42 shows the design of the camshaft carrier, which bears the intake and exhaust camshaft as well as the cam followers and the upper chain guide.

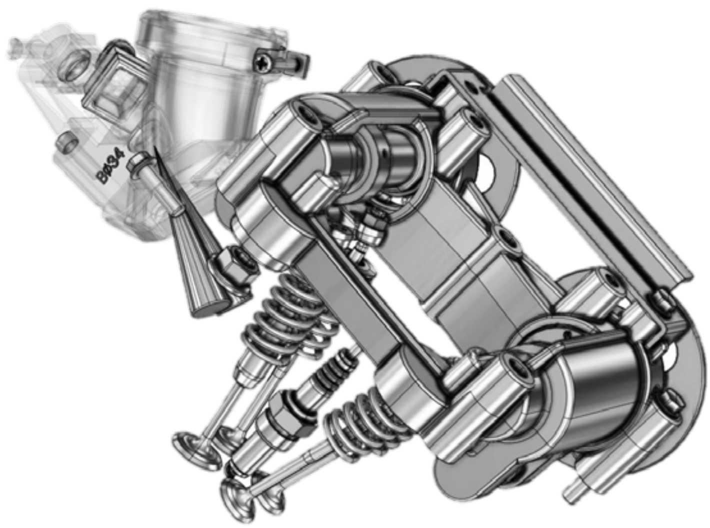

Fig. 42: Valve Train Carrying System (XY150)[206]

[205] FVT (2012d), p.104
[206] FVT (2012d), p.104

Despite the common set ups for DOHC engines, the separation plane was set below the camshaft axes. This enables the use of a separate part to carry both camshafts and cam followers, without split bearings (see Fig. 43)

By means of this design, it is no longer necessary to machine the cylinder head together with the mounted split bearing shells. The camshaft carrier is one part, which can be machined completely in advance. After that, it is possible to pre-assemble all valve train components such as camshafts and cam followers and mount to the cylinder head later on.

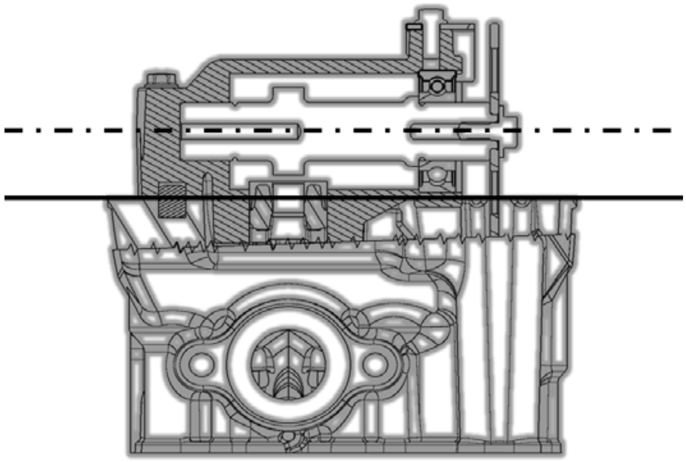

Fig. 43: Split Plane Location of Cylinder Head (XY150)[207]

4.9 Work Step 8 “Presentation of Proposals”

The concepts described in work step 7 are presented to the customer management. The management reviewed the concepts and rated them positively and decided to release the design of XY150 for prototyping. the idea to integrate a camshaft carrier, which provides the possibility to preassemble the camshafts outside of the cylinder head, was especially well received.

4.10 Work Step 9 “Implementation“

After the decision to implement the proposed concept for the XY150 cylinder head assembly, the detailed design phase started. When the design of the first parts was finished, engineers of FVT and the customer visited the IMT-C manufacturing site in Krenglbach (Upper Austria). In the meeting with the head of IMT-C the first

[207] FVT (2012d), p.105

components were checked to see if they were ready for production. The first parts to be manufactured by IMT-C are the cylinder head, the cylinder head cover, the camshaft carrier and the cylinder. In further steps, other components are manufactured and standard parts are purchased. The first prototype of the complete XY150 engine, including the newly designed cylinder head assembly is completed in November 2013.

4.11 Lessons Learned and Potential for Improvements

People from different cultures work together on an international project. Therefore, mutual understanding is very important because often things that are self-evident for someone, are completely new to another colleague.

An important criterion for the customer is the strict compliance to the timetable, which of course contains considerable potential for conflict when it comes to delays. For example, the customers' engineers begun to plan tools for mass production before the design phase was completed. But really, it makes no sense to plan tools if the components are not designed in detail and if the parts need to be changed during prototype testing.

Furthermore, the customers' engineers have the notion that, after the design phase, the product corresponds one hundred percent to the final product. However, experience shows that during the prototype test phase, many changes need to be integrated to an engine.

For the VA project, it should be noted that the timing of the application has been too late. Actually, VA needs to be implemented at the beginning of the design phase and not towards the end. Nevertheless, the conduction of the VA project was useful for the employees to learn the basic procedure and the tasks during the different steps of the VA work plan. Additionally, the Functional Analysis (FA) and the function cost brought new insights to project team members in terms of costs.

Feedback of Project Team Members

Generally, the project team members were very positive towards VA. Unfortunately, the time capacities for the VA project were quite low and therefore, an intensive examination with the method VA was not possible for the project team members.

The project team members stated that VA is really an interesting method for improvement for products as well as for the development of new products. The holistic approach that opens different prespectives to the VA object, which are not considered in the work of an engineer and the systematic procedure according to the VA work plan, are named as especially big advantages.

Through the work with functions, the common understanding of the VA objects has increased. The Function Analysis (FA) is a tool, which should be used for every design project. As the idea of finding out the functions of an object before searching for solutions is an approach, which is not very common in the real work life of an engineer.

Also, the ABC Analysis was not yet known in the FVT desgin department. The graphical representation of the cost drivers provides a good overview of the cost structure of the VA object and it can be easily seen where the focus on improvements should lie.

4.12 Summary

Chapter 4 describes the practical application of the method Value Analysis, which provides the basis for the optimization of selected components of a motorcycle engine in terms of functionality and cost. Firstly, with the application of an ABC Analysis, the most valuable parts of a motorcycle engine are filtered out. The cylinder head assembly is selected and then subjected to Value Analysis according to the ABC Analysis results. Thereby, the newly designed parts are optimized and compared with an existing engine for benchmarking reasons. The work plan according to EN 12973 is used to ensure a structured proceeding of the Value Analysis project.

The process of Functional Analysis is used to obtain a complete description of the functions of the cylinder head assembly and their relationships, which are systematically represented in a function tree. Afterwards, the cost of all parts of the cylinder head assembly are allocated to the functions and illustrated in a function cost matrix. Subsequently, for all functions, the degree of functional performance is evaluated according to the given requirements. The result is the target cost of the newly designed cylinder head assembly of the motorcycle engine.

To achieve the determined target cost and satisfy all customer requirements at the same time, a global solution concept is developed. Finally, the various ideas that are integrated in the new design of the cylinder head assembly are presented and the respective cost is compared with the evaluated target cost.

5 Review and Outlook

The diploma thesis entitled "Cost Assessment and Optimization in the Front-End of the Design and Development Process of a Motorcycle Engine" deals with the practical application of the Value Analysis (VA) method in an international product development project. The VA method, with its systematic, holistic and value-based management approach provides the basis for the optimization of selected components of a motorcycle engine in terms of functionality and cost. Firstly, with the application of an ABC Analysis, the most valuable parts of a motorcycle engine are filtered out. According to the ABC Analysis results, the cylinder head assembly is selected and then subjected to Value Analysis. Thereby, the newly designed parts are optimized and compared with an existing engine for benchmarking reasons. The work plan according to EN 12973 is used to ensure a structured proceeding of the Value Analysis project.

The core element of Value Analysis is the Functional Analysis (FA). The process of FA is used to obtain a complete description of the functions of the cylinder head assembly and their relationships, which are systematically represented in a function tree. Afterwards, the cost of all parts of the cylinder head assembly are allocated to the functions and illustrated in a function cost matrix. Subsequently, the degree of functional performance is evaluated according to the given requirements for all functions. The result is the target cost of the newly designed cylinder head assembly of the engine.

To achieve the determined target cost and satisfy all customer requirements at the same time, a global solution concept is developed. Finally, various ideas that are integrated in the new design of the cylinder head assembly are presented and the respective cost is compared with the evaluated target cost.

The result shows that the estimated cost for the XY150 is only 2.2 percent higher than the target cost. This is a good result when considering the higher amount of components (14.3 percent) and the increased weight of 1496 grams (47.6 percent) compared to the benchmark cylinder head assembly. Furthermore, the new XY150 cylinder head assembly has a nice appearance, state of the art technology, higher performance and efficiency. Additionally, machining steps and machining directions are saved as well as the mounting of the camshafts is facilitated.

For the VA project, it has to be noted that the timing of the application has been too late. Actually, VA needs to be implemented at the beginning of the design phase and not towards the end. Nevertheless, the conduction of the VA project was useful for the employees to learn the basic procedure and the tasks during the different steps of the VA work plan. In addition, FA and the function cost analysis brought new insights to project team members in terms of costs. With the gained knowledge and the written report as a basis, it should be possible for them to independently conduct another VA project within the Research Institute for Internal Combustion Engines and Thermodynamics Ltd. The main two challenges are the right moment for the start of the VA project and the provision of enough time capacity for the engineers to conduct such a project.

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Table of Abbreviations

BOM	Bill of Material
CFD	Computational Fluid Dynamics
DOHC	Double Overhead Camshaft
EFI	Electronic Fuel Injection
FA	Functional Analysis
FMEA	Failure Mode and Effects Analysis
FVT	Research Institute for Internal Combustion Engines and Thermodynamics Ltd.
IBL	Institute of Industrial Management and Innovation Reasearch
IVT	Institute for Internal Combustion Engines and Thermodynamics
QFD	Quality Function Deployment
QTY	Quantity
SAVE	Society of American Value Engineers
SOHC	Single Overhead Camshaft
TBD	To Be Defined
TUG	Graz University of Technology
VA	Value Analysis
VDI	Verein Deutscher Ingenieure (English: Association of German Engineers)
VE	Value Engineering
VM	Value Management
WIFI-ZWA	Economic Development Institute of the Economic Chamber Austria

Appendix A: Value Analysis Work Plan (EN 12973)

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
0 Preliminary phases	0.1 Project outline		
	0.2 Feasibility investigation, risk analysis	These are high level and short studies	Cost-estimating models (for development, for production)
	0.3 Profitability investigation, what is at stake		
	0.4 Decision-maker and VA project leader selection		* Definition of VA project leader requirements
1 Project definition	1.1 The subject		
	1.2 Framework of the study	Coherence with the organisation strategy Laws, regulations Constraints Scope and limits of the study	
	1.3 Premises of the data about problem	Needs to be satisfied Market Competition	
	1.4 Marketing objectives	Position relative to competition (price, performances attained, advantage over competition)	

"to be continued"

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
	1.5 General objectives	Cost or cost reduction (development, production) Dependability (reliability, safety, maintainability, availability) Return on investment rules for decisions and selections Allowance of time	
	1.6 What is at stake	From a strategic and economic point of view	
	1.7 Resources	Manpower, equipment	
	1.8 Participants	Fundamental guidelines and general instructions only (this matter has to be considered in de-tail when constituting the working team)	
	1.9 Preliminary risk analysis	The risks brought about by the project, those brought about by the product	
2 Planning	2.1 Constituting a working team	According to the problem, the team may also be created during phases 3 and 4	* Rules applying to the composition of VA teams
	2.2 Working out an initial time schedule		
	2.3 Agreeing venue for work		

"to be continued"

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
3 Gathering comprehensive data about the study	3.1 Information gathering (internal, and external) : - technical information (about the product) ; - economic - about competition ; - state of art (technology).	Typical sources : - After-sales ; - Gathering of field experience ; - Technical manual.	
	3.2 Detailed market survey : - customer requirements ; - the market ; - determination of the position of the product to be developed.	Comparative to competition (internal and external)	
	3.3 Miscellaneous : - bibliography ; - patents ; - laws and regulations, standards ; - organisation's rules, manuals, standards, etc.	As a source of information, of constraints	

"to be continued"

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
4 Functional analysis, cost analysis, detailed objectives	4.1 Expression of need and functional analysis	Structuring and hierarchical ordering of functions, establishment of the function structure Functions characterisation Key functions compared to competition	* Functional analysis techniques * Organising the functions (trees, FAST diagrams) * Functional Performance Specification (see section A.1.4) * Evaluation criteria, their levels, cost variation claimed or accepted for a variation in a level * Techniques for the establishment of function costs Dependability studies (and among them : need FMECA, risk analysis)
	4.2 Cost analysis and function cost		
	4.3 Fixing detailed objectives and evaluation criteria	Within the global objectives set by Management	
5 Gathering and creation of solution ideas	5.1 Gathering of existing ideas		
	5.2 Creation of new ideas	Successive consideration of : - a global arrangement of proposals ; - more detailed solutions for the concepts that are being contemplated	Creativity techniques Organisation of PRFs
	5.3 Critical analysis	Search for possible useless or undesirable functions	

"to be continued"

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
6 Evaluation of solution ideas	6.1 Evaluation of ideas, combining them		Cost estimating models
	6.2 Choice of what is to be developed		
	6.3 Work programmes for development		
7 Development of global proposals	7.1 Studies, tests, industrial development	This is within the scope of the regular activities of the organisation	
	7.2 Follow-up, coordination		
	7.3 Evaluation of the solutions : - qualitatively ; - economically ; - risk analysis.	Considering the functions and the levels obtained for the different evaluation criteria (see 6.2.4)	
8 Presentation of proposals	8.1 Selection of the solutions to be proposed		
	8.2 Working out of implementation programmes		
	8.3 Organising comprehensive data about the proposal		
	8.4 Obtaining a decision from the decision-maker		
	8.5 Keeping the VA team informed and either dismissing or putting it on stand-by		

"to be continued"

Basic Phases	Elementary Steps	Comments on the elementary steps	The tools used * specific VM tools
9 Implementation	9.1 Support of the implementation : - follow -up ; - possible assistance to correct deviations, or for adaptations.	The operative departments of the company are normally in charge of the implementation itself	
	9.2 On exceptional occasions, organisation of other meetings of the VA team to tackle an unexpected problem (reactivation)		
	9.3 Assessing the actual results of the implementation, comparing them with the prospective results	Or participation in the establishment of this assessment (prospective results were evaluated in elementary steps 0.3 and 7.3)	
	9.4 Disseminating the assessment of the actual results and the technical and general information : - to the VA team members ; - to the experts concerned ; - more widely in the organisation.	Particularly for motivation purposes	
	9.5 Perhaps establishment of a system to collect information about field experience		

Appendix B: Function Cost Matrices (YZF125/XY150)

Function Tree				Cylinder Head Assembly YZF125 - Function Carrier																																						
Main function	1. Auxiliary function	2. Auxiliary function	3. Auxiliary function	1 Cylinder head	2 Cylinder head gasket	3 Cylinder head center sleeve	4 Cylinder head cover	5 Cylinder head cover gasket	6 Cylinder head cover bolt M6x15	7 Intake valve seat	8 Exhaust valve seat	9 Intake Valve	10 Exhaust Valve	11 Intake valve guide	12 Exhaust valve guide	13 Valve stem seal	14 Valve spring	15 Spring seat	16 Valve carrier	17 Valve carrier collet	18 Intake rocker arm	19 Exhaust rocker arm	20 Rocker arm shaft	21 Camshaft	22 Camshaft bearing 6906	23 Camshaft bearing 6001Z	24 Sprocket	25 Sprocket bolt M8x25	26 Sprocket pin	27 Locking plate	28 Locking plate screw M6x15	29 Decompressor	30 Spark plug NGK R	31 Coolant temperature sensor	32 Thermostat	33 Thermostat cover	34 Thermostat cover bolt M6x20	35 Oil locking screw M6x15	36 Copper oil sealing washer	Function Cost [EUR]	Function Cost [%]	Ranking
1 Exchange charge	1.1 Supply fresh gas	1.1.1 Pass fresh gas		12% € 4.62						20% € 0.24																														€ 4.86	4.05%	11
		1.1.2 Control fresh gas supply	1.1.2.1 Open combustion chamber									29% € 1.03																												€ 1.03	0.86%	19
			1.1.2.2 Close combustion chamber							10% € 0.12		29% € 1.03					25% € 0.56																							€ 1.71	1.43%	15
	1.2 Discharge exhaust gas	1.2.1 Pass exhaust gas		12% € 4.62							20% € 0.24																													€ 4.86	4.05%	11
		1.2.2 Control exhaust gas discharge	1.2.2.1 Open combustion chamber										29% € 0.96																											€ 0.96	0.80%	20
			1.2.2.2 Close combustion chamber								10% € 0.12		29% € 0.96				25% € 0.56																							€ 1.64	1.37%	16
2 Control combustion process	2.1 Initiate combustion																																95% € 5.70							€ 5.70	4.74%	8
	2.2 Form combustion chamber			3% € 1.16								2% € 0.07	2% € 0.07																											€ 1.29	1.07%	17
	2.3 Position valves									10% € 0.12	10% € 0.12						50% € 1.13				50% € 4.25	50% € 4.25		68% € 6.80			90% € 3.81													€ 20.48	17.04%	2
	2.4 Position spark plug			6% € 2.31																																				€ 2.31	1.92%	13
3 Control thermal balance	3.1 Transfer heat			2% € 0.77																																				€ 0.77	0.64%	21
	3.2 Pass cooling medium			22% € 8.47																																				€ 8.47	7.05%	5
	3.3 Measure temperature																																	100% € 1.84						€ 1.84	1.53%	14
	3.4 Control flow rate																																		100% € 9.00					€ 9.00	7.49%	3
4 Ensure lifespan	4.1 Withstand corrosion			3% € 1.16																																				€ 1.16	0.96%	18
	4.2 Minimize wear			4% € 1.54						30% € 0.37	30% € 0.37	30% € 1.07	30% € 0.99					60% € 0.10		70% € 0.26			20% € 0.51	12% € 1.20																€ 6.39	5.32%	6
5 Offer comfort	5.1 Meet maintenance requirements																				30% € 2.55	30% € 2.55											5% € 0.30							€ 5.40	4.49%	9
	5.2 Facilitate starting process																															100% € 5.00								€ 5.00	4.16%	10
6 Absorb forces				5% € 1.93					100% € 0.30										30% € 0.32	30% € 0.11			20% € 0.51		100% € 1.17	100% € 0.62		100% € 0.07	50% € 0.10	20% € 0.40	100% € 0.12						100% € 0.14	100% € 0.06		€ 5.84	4.86%	7
7 Take elements				22% € 8.47		100% € 0.10	47% € 1.18					10% € 0.36	10% € 0.33	100% € 0.84	100% € 0.84			40% € 0.06	70% € 0.74		20% € 1.70	20% € 1.70	60% € 1.52	20% € 2.00			10% € 0.42		50% € 0.10	80% € 1.60						50% € 0.75				€ 22.71	18.89%	1
8 Dense components				9% € 3.47	100% € 0.76		47% € 1.18	100% € 0.80		30% € 0.37	30% € 0.37					100% € 0.84																				50% € 0.75			100% € 0.10	€ 8.62	7.17%	4
9 Satisfy styling demands							6% € 0.15																																	€ 0.15	0.12%	22
			Part cost	€ 38.50	€ 0.76	€ 0.10	€ 2.50	€ 0.80	€ 0.30	€ 1.22	€ 1.22	€ 3.55	€ 3.31	€ 0.84	€ 0.84	€ 0.84	€ 2.25	€ 0.16	€ 1.06	€ 0.37	€ 8.50	€ 8.50	€ 2.53	€ 10.00	€ 1.17	€ 0.62	€ 4.24	€ 0.07	€ 0.20	€ 2.00	€ 0.12	€ 5.00	€ 6.00	€ 1.84	€ 9.00	€ 1.50	€ 0.14	€ 0.06	€ 0.10	**€ 120.21**	100%	
			Check sum	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	**€ 120.21**		

Function Tree / Cylinder Head Assembly XY150 - Function Carrier

Main function	1. Auxiliary function	2. Auxiliary function	3. Auxiliary function	1 Cylinder head	2 Cylinder head gasket	3 Cylinder head center sleeve	4 Cylinder head cover	5 Cylinder head cover gasket	6 Cylinder head cover bolt	7 Cylinder head cover washer	8 Intake valve seat	9 Exhaust valve seat	10 Intake Valve	11 Exhaust Valve	12 Intake valve guide	13 Exhaust valve guide	14 Valve stem seal	15 Valve spring	16 Spring seat	17 Valve carrier	18 Valve carrier collet	19 Intake cam follower	20 Exhaust cam follower
1 Exchange charge	1.1 Supply fresh gas	1.1.1 Pass fresh gas		12% € 5.28							20% € 0.24												
		1.1.2 Control fresh gas supply	1.1.2.1 Open combustion chamber										29% € 1.03										
			1.1.2.2 Close combustion chamber								10% € 0.12		29% € 1.03					25% € 0.56					
	1.2 Discharge exhaust gas	1.2.1 Pass exhaust gas		12% € 5.28								20% € 0.24											
		1.2.2 Control exhaust gas discharge	1.2.2.1 Open combustion chamber											29% € 0.96									
			1.2.2.2 Close combustion chamber									10% € 0.12		29% € 0.96				25% € 0.56					
2 Control combustion process	2.1 Initiate combustion																						
	2.2 Form combustion chamber			3% € 1.32									2% € 0.07	2% € 0.07									
	2.3 Position valves										10% € 0.12	10% € 0.12						50% € 1.13				50% € 4.25	50% € 4.25
	2.4 Position spark plug			6% € 2.64																			
3 Control thermal balance	3.1 Transfer heat			2% € 0.88																			
	3.2 Pass cooling medium			22% € 9.68																			
	3.3 Measure temperature																						
	3.4 Control flow rate																						
4 Ensure lifespan	4.1 Withstand corrosion			3% € 1.32																			
	4.2 Minimize wear			4% € 1.76							30% € 0.36	30% € 0.36	30% € 1.07	30% € 0.99					60% € 0.10		70% € 0.26		
5 Offer comfort	5.1 Meet maintenance requirements																					30% € 2.55	30% € 2.55
	5.2 Facilitate starting process																						
6 Absorb forces				5% € 2.20					50% € 0.35											30% € 0.32	30% € 0.11		
7 Take elements				20% € 8.80		100% € 0.10	10% € 0.40	10% € 0.10	50% € 0.35	50% € 0.05			10% € 0.36	10% € 0.33	100% € 0.84	100% € 0.84			40% € 0.06	70% € 0.74		20% € 1.70	20% € 1.70
8 Dense components				9% € 3.96	100% € 0.76		70% € 2.80	90% € 0.90		50% € 0.05	30% € 0.36	30% € 0.36					100% € 0.84						
9 Satisfy styling demands				2% € 0.88			20% € 0.80																
			Part cost	€ 44.00	€ 0.76	€ 0.10	€ 4.00	€ 1.00	€ 0.70	€ 0.10	€ 1.21	€ 1.21	€ 3.55	€ 3.31	€ 0.84	€ 0.84	€ 0.84	€ 2.25	€ 0.16	€ 1.06	€ 0.37	€ 8.50	€ 8.50
			Check sum	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Function	21 Cam follower shaft	22 Intake camshaft	23 Exhaust camshaft	24 Camshaft bearing 6004	25 Camshaft bearing 6001Z	26 Camshaft carrier	27 Camshaft carrier center sleeve	28 Camshaft carrier screw M6x60	29 Sprocket	30 Sprocket bolt M8x25	31 Feather key	32 Chain guide	33 Chain guide screw M6x15	34 Decompressor	35 Spark plug NGK R	36 Coolant temperature sensor	37 Thermostat	38 Thermostat cover	39 Thermostat cover bolt M6x20	Function Cost [EUR]	Function Cost [%]	Ranking
1.1.1 Pass fresh gas																				€ 5.52	3.70%	10
1.1.2.1 Open combustion chamber																				€ 1.03	0.69%	20
1.1.2.2 Close combustion chamber																				€ 1.71	1.15%	16
1.2.1 Pass exhaust gas																				€ 5.52	3.70%	10
1.2.2.1 Open combustion chamber																				€ 0.96	0.64%	21
1.2.2.2 Close combustion chamber																				€ 1.64	1.10%	17
2.1 Initiate combustion															95% € 5.70					€ 5.70	3.82%	9
2.2 Form combustion chamber																				€ 1.46	0.98%	18
2.3 Position valves		68% € 4.33	88% € 6.34						90% € 7.62											€ 28.15	18.89%	2
2.4 Position spark plug																				€ 2.64	1.77%	13
3.1 Transfer heat																				€ 0.88	0.59%	22
3.2 Pass cooling medium																				€ 9.68	6.49%	4
3.3 Measure temperature																100% € 1.84				€ 1.84	1.23%	14
3.4 Control flow rate																	100% € 9.00			€ 9.00	6.04%	5
4.1 Withstand corrosion																				€ 1.32	0.89%	19
4.2 Minimize wear	20% € 0.51	12% € 0.76	12% € 0.86			10% € 1.00														€ 8.03	5.39%	6
5.1 Meet maintenance requirements						10% € 1.00									5% € 0.30					€ 6.40	4.29%	8
5.2 Facilitate starting process														100% € 5.00						€ 5.00	3.35%	12
6 Absorb forces	20% € 0.51					15% € 1.50		100% € 0.40		100% € 0.16	50% € 0.12	20% € 0.60	100% € 0.12						100% € 0.14	€ 6.53	4.38%	7
7 Take elements	60% € 1.52	20% € 1.27		100% € 2.34	100% € 1.24	65% € 6.50	70% € 0.14		10% € 0.85		50% € 0.12	80% € 2.40						45% € 0.68		€ 33.43	22.43%	1
8 Dense components							30% € 0.06											45% € 0.68		€ 10.77	7.23%	3
9 Satisfy styling demands																		10% € 0.15		€ 1.83	1.23%	15
Part cost	€ 2.53	€ 6.37	€ 7.20	€ 2.34	€ 1.24	€ 10.00	€ 0.20	€ 0.40	€ 8.47	€ 0.16	€ 0.24	€ 3.00	€ 0.12	€ 5.00	€ 6.00	€ 1.84	€ 9.00	€ 1.50	€ 0.14	€ 149.05	100%	
Check sum	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	€ 149.05		