Product Development Strategies for Entering the Thermal Analysis Market

Diploma Thesis

by

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STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used 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, 17th December 2010

(signature)

Abstract

This work aims to provide product development strategies that enable the Austrian company Anton Paar GmbH access to the global market in the field of thermal analysis. In order to develop a strategy suitable for the company, a structured approach is used in which information is gathered on different thermal analysis methods and their practical application possibilities. Subsequently, an analysis of the thermal analysis market considers different aspects like total market size and the potential for market development. A comprehensive competitive analysis focuses on dynamic mechanical analysis method. The information gained provides an overview of the price policy, product strategies and market share of different competitors. The comparison of two product development strategies leads to a recommendation given to the company. From today´s perspective, the expansion of the existing product range by a new instrument which combines rheological methods with dynamic mechanical analysis is recommended.

Kurzfassung

Das Ziel dieser Arbeit ist die Konzeption von Produktentwicklungsstrategien, die dem österreichischen Unternehmen Anton Paar GmbH einen Eintritt in den weltweiten Thermoanalysemarkt ermöglichen. Um eine für das Unternehmen geeignete Strategie zu entwickeln, wird ein strukturiertes Vorgehensmodell gewählt, bei dem zu Beginn Informationen über verschiedene Thermoanalysemethoden und deren praktische Anwendungsmöglichkeiten gesammelt werden. Die Analyse des gesamten Thermoanalysemarktes berücksichtigt daraufhin verschiedene Aspekte wie Gesamtmarktgröße und Marktentwicklungspotenzial. Eine umfassende Wettbewerbsanalyse konzentriert sich auf den Bereich des dynamisch-mechanischen Thermoanalyseverfahrens. Die im Zuge der Wettbewerbsanalyse gewonnen Informationen verschaffen dabei einen Überblick über Preispolitik, Produktstrategien und Marktanteile verschiedener Wettbewerber. Aus der Gegenüberstellung zweier Produktentwicklungsstrategien wird eine Empfehlung für das Kooperationsunternehmen abgeleitet. Dabei ist aus heutiger Sicht die Erweiterung der vorhandenen Produktpalette um ein neues Gerät, welches rheologische Messverfahren und Verfahren der dynamisch-mechanischen Thermoanalysemethode in einem Messgerät vereint, empfehlenswert.

I want to dedicate this work to…
my love Carla
my parents
…whose ideas and actions have enriched my life.

Table of contents

1 Introduction

Research and innovation are key drivers for a high performance and competitiveness of companies in Austria. Investments in research and development will also make an important contribution in future to ensure the competitiveness of companies in an international environment.[1]

According to survey results from Statistik Austria, the corporate sector increased its spending on research and development by over 55 % in the period of 2002-2007 (see also Table 1.1). Final data for the year 2010 have not been available at the end of this work, but it was expected to have an increase of R&D spending compared with the same period of the previous year, as published in the Austrian Report on science and Technology. Despite the worldwide economic crisis in 2009, the importance of technology and innovation for companies in a competitive environment remains unchanged.[2,3]

Table 1.1 Spending on research and development in Austria, 2002-2007[4]

	Spending on Research and Development [Million €]			
Sector	**2002**	**2004**	**2006**	**2007**
Corporate sector	3.131	3.556	4.449	4.846
Total	4.684	5.250	6.319	6.868

The Austrian company Anton Paar GmbH[5] follows this positive trend and spends approximately 20 % of its annual turnover on research and development.[6] In this context, the company aims on having a sustainable growth by strengthening its own innovation capacity. Thermal analysis hereby has been identified as a potential field for corporate growth. The main goal of this thesis was to find product development strategies which support the company´s decision making process whether and how to enter the market of thermal analysis.

[1] Bundesministerium für Wissenschaft und Forschung, 2010, pp. 3-72
[2] STATISTIK AUSTRIA, 2009, retrieved December 07, 2010, from http://www.statistik.at/web_de/static/ausgaben_fuer_forschung_und_experimentelle_entwicklung_1993_bis_2007_nach__023530.pdf
[3] Bundesministerium für Wissenschaft und Forschung, 2010, pp. 18-24
[4] Data aggregated from STATISTIK AUSTRIA, 2009, retrieved December 07, 2010, from http://www.statistik.at/web_de/static/ausgaben_fuer_forschung_und_experimentelle_entwicklung_1993_bis_2007_nach__023530.pdf
[5] Note that in the following "Anton Paar" is synonymously used for the entire group.
[6] Anton Paar GmbH – company presentation, 2009, p. 6

1.1 Background

Anton Paar GmbH produces high-end measuring and laboratory instruments for industry and research.[7] It is an innovative Austrian company headquartered in Graz, Styria. Openness to the requirements of customers and attention to developments in markets are the basis for new product ideas. Thus, Anton Paar is planning to expand its business activities into certain areas of thermal analysis.

Getting close to the customer to identify their requirements and needs has already been one of the company's success factors. As a result, certain customer requirements were detected in the field of monitoring physical properties with change of temperature. This led to the idea of serving the market also with well-designed thermal analysis measuring devices.

To continue this idea, following key questions had to be answered in advance:

1. What are the main principles of thermal analysis? What can the thermal analysis methods be used for and which areas will be considered more in detail?
2. What are the core competencies and the competitive advantages of Anton Paar?
3. How can the thermal analysis market be defined? Who are the main customers, competitors and rule-makers in this market?
4. How can a successful product development look like and what impacts and consequences result out of that?

1.2 Objective of the work

The primary objective of this work is to establish a strategy for developing a new product in the field of thermal analysis. Input for this strategy will include information regarding the technology, the market, the capabilities, the customers as well as the competitors. Derived from the questions in chapter 1.1, following sub-targets will cover the content of this work:

1. Overview of thermal analysis encompassing:
    - Existing measuring principles, but narrowed down to most common used ones
    - Practical applications of thermal analysis in different industries

[7] Anton Paar GmbH – presentation folder, 2009, p. 1

2. Identification of Anton Paar´s product portfolio and determining the overlap to different fields, which are as follows:
    - Overlap of the company´s competencies with fields from thermal analysis
    - Demonstration of the company´s current situation whether there is a close relationship of industries served by Anton Paar to fields from thermal analysis

3. Determination of the attractiveness of the market:
    - Estimation of overall market size and selection of one market segment that will be focused on
    - Conducting a competitive analysis, where
        - the competitors on the market including their market shares will be identified and
        - their product portfolio will be analysed.

4. Working out a strategy for new product development that will include:
    - Concept development of new product on thermal analysis market
    - Comparison of relevant approaches to derive one recommendation for corporate development

1.3 Structure of the thesis

The present thesis concerns strategies for a new product development whereas special consideration was given to the business environment of Anton Paar. In this work, a structured approach is used to consider different aspects of product development systems for accessing the market of thermal analysis. The structured approach is characterised by four phases which are described in detail below. Figure 1.1 also represents schematically the structure of the thesis.

Part 1:
An overview of thermal analysis measuring principles is given in the first part. The focus is on important application areas and relevant industries for Anton Paar. In continuation, practical examples show how thermal methods are applied in various industries.

Part 2:
In the second part, the core competencies and the competitive advantages of Anton Paar are identified. This covers the current product range of Anton Paar, the existing

technological know-how that is closely related to the thermal analysis methodology and the suitability of the existing sales and service network.

The overlap of their competencies with fields from thermal analysis shows to which technology the company has already access to. Furthermore, all industries are demonstrated which are currently served by Anton Paar and which ones are coherent to the fields of thermal analysis.

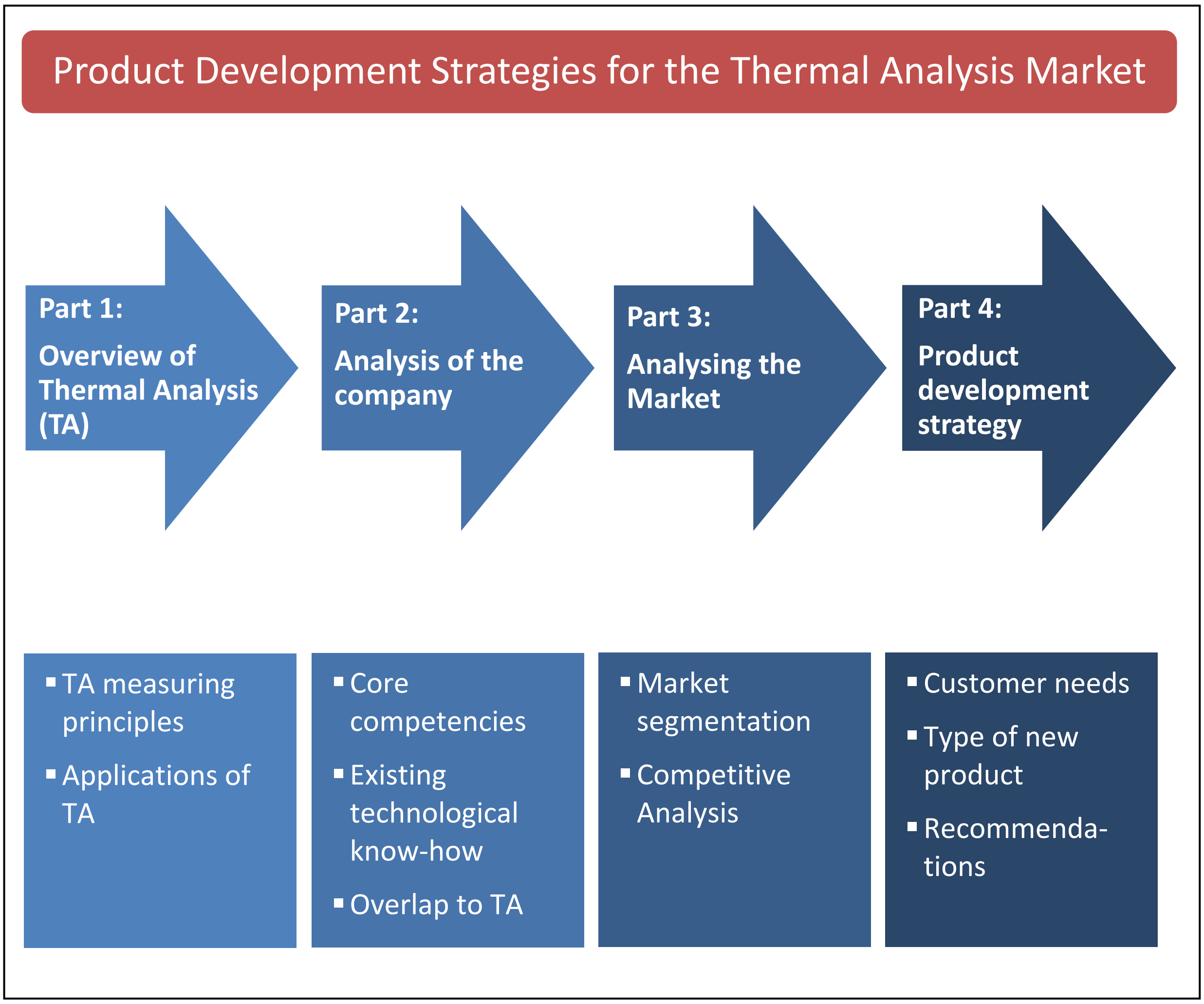

Figure 1.1 Structure of the thesis[8]

Part 3:

The goal of the market analysis in part 3 is to determine the attractiveness of the market. Therefore, the market size and the share of different market segments are determined and future market trends are assessed. The target market selection process has the aim to figure out one market segment that will be particularly focused on. A detailed competitive analysis

[8] Own illustration

is carried out afterwards. The main competitors in the target market are identified and their corresponding products and applications analysed.

Part4:
In a final step the customer requirements and needs are identified by applying existing knowledge to the new concept and learning from competitors´ strategies. In the last part of the work, a developing strategy for a new product is worked out. Thereby, following approaches are considered in detail: Whether to extend the existing product line of Anton Paar or to design a complete new product. Corresponding tools are selected and applied to evaluate these strategic choices and finally a recommendation is derived as to which strategy should be selected.

1.4 **Company profile of Anton Paar**[9]

Anton Paar GmbH produces and distributes high-quality measuring and analytical instruments for industry and research. At the moment, Anton Paar offers a wide product range including density and concentration measuring devices, rheometers and viscometers and other measuring devices for solids and liquids. In the field of density measurement, Anton Paar is ranked number one in the world. Chapter 4.3 provides an overview about the current product portfolio of Anton Paar.

1.4.1 **Historical overview**[10]

Anton Paar GmbH was founded in 1922 by Mr. Anton Paar, a master locksmith, who cooperated with various companies, universities and research institutes at that time. In 1932, the daughter of Anton Paar, Margarethe Platzer, took over the business. She also established the company´s first scientific, analytical instrument which was a small angle X-ray camera. In 1963, Mr. Ulrich Santner becomes CEO of the company and also takes responsibility to market the company´s products internationally. The development of the revolutionary oscillating U-tube principle for density measurements represented an important milestone for the company in the late 1960s. Since then, the company introduced many new analytical instruments on the market and continued a close cooperation with various universities and research institutes.

[9] Anton Paar GmbH – presentation folder, 2009, pp. 1-22
[10] Anton Paar GmbH – presentation folder, 2009, p. 2

1.4.2 Anton Paar key figures[11]

The following data, facts and figures from 2009 give an overview of the company´s structural organisation.

Company structure

Founded:	1922
Owned by:	Santner Foundation (charitable foundation)

Management

CEO:	Dr. Friedrich Santner
Board of Directors:	Chairman: Ulrich Santner

Company data

Employees:	Over 1100 worldwide
Turnover (2009):	EUR 102,1 million
R&D expenditures:	Approximately 20% of turnover

Anton Paar worldwide

Sales network:	110 partners worldwide
Export share:	> 90%

[11] Anton Paar GmbH – Company presentation, 2009, p. 6

2 Theoretical Framework of the Study

In this work, various theoretical considerations have been used for addressing the main issues of product development strategies. The approaches and theories considered in this work are explained in the following chapter. A closer look will be taken on the topic of core competencies and how they can be identified in companies. In continuation, the technology portfolio is considered more in detail as it provides a structured approach for selecting one technology in the case study of Anton Paar. Porter´s five forces framework and different models of a product development process constitute the end of this chapter.

2.1 The core competencies[12]

The core competencies model developed by HAMEL/PRAHALAD explains the importance of collective learning in an organization and the relevance of coordination skills for production. Core competencies are the source for gaining competitive advantage by the management´s ability to bundle the technologies and production skills within an organization into competencies which enable a fast reaction to changing demands and conditions.
This model also will be adopted for the purpose of analysing the past success factors of Anton Paar and how core competencies also contribute to achieve competitive advantage in the future. Identified core competencies of Anton Paar will be described later in chapter 4.2.

Main factors for identification of core competencies
According to Hamel and Prahalad, there are three main factors to identify core competencies in a company:

1. **Providing access to different markets:** Core competencies should provide access to a broad variety of markets. One core competence can help to develop core products which serve not only one market but different distinguished markets like for example consumer electronics, computer components and even automotive market.
2. **Customer benefit:** Core competencies are skills used in business to provide customers a special benefit, the delivery of value from the customer´s view. The idea is to provide consistent arguments for the customers why to prefer one product over another.
3. **Difficulty of imitation:** Existing core competencies in an organisation should be difficult to imitate for its competitors. Skills and capabilities are considered to be "unique" and not easily transferred to another business or acquired from competitors.

[12] Prahalad and Hamel, 1990, pp. 79-90

Derived from that concept, core competence might not be associated with cost sharing by use of common facilities nor is it a question of increase spending on research and development. Core competencies are more related to processes or products of a company which are difficult to imitate for its competitors and hence differentiate a company strategically.

Identifying core competencies

For the process of identifying core competencies it is crucial to have a structured approach. The two-step approach described below can be considered as a summarised form from Mind Tools Ltd.[13]

1. Brainstorming of factors which are important from the customer´s perspective. This should include all arguments used by the customer why they have bought one certain product - or vice versa - which are the critical points to convince the customer.

2. Identification of own competencies where the company is good in and review the existing competencies and the list of factors that are important for customers. All factors are screened and compared with the three factors of core competencies according to Hamel and Prahalad subsequently.

2.2 Market segmentation

Market segmentation is the process of dividing the market into different groups.[14] Customers have different requirements concerning the product, so the market segmentation process can help to find similarities in one group of customers or users.[15] Hence, segmentation can be useful to assign potential customers to homogenous groups.[16]

Because the needs, preferences and requirements of consumers and business customers are not similar, the concept of market segmentation uses a set of variables or characteristics to distinguish between these two groups.[17]

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[13] Mind Tools Ltd, retrieved December 05, 2010, from http://www.mindtools.com/pages/article/newTMC_94.htm
[14] Kotler, 2002, p. 144
[15] Johnson, Scholes and Whittington, 2005, p. 91
[16] Wedel and Kamakura, 2000, p. 7
[17] Kotler, 2002, p. 147

2.2.1 Segmentation of consumer markets[18]

For the segmentation of consumer markets, the market segments can be distinguished in geographic, demographic, psychographic and behavioural characteristics.

Geographic Segmentation
In geographic segmentation, the market is divided into different geographical conditions. Distinguishing criteria can be nations, states, regions, cities or even climate regions. A company can decide to be active in one single or in a few geographic regions or to operate in all. Important for the latter consideration is the adaption on local circumstances.

Demographic Segmentation
The segmentation of markets based on demographic information is a widely used method to determine the demand or the buying behaviour of consumers. With this segmentation method it is possible to draw conclusions about the total size of the market and how potential customers can be addressed.
Some of demographic variables often used in segmentation are age and life-cycle stage, gender, level of income, generation or social class.

Psychographic Segmentation
In psychographic segmentation, groups of customers are formed according to their lifestyle, activities or interests. Variables which are used in psychographic segmentation can include lifestyle to reflect the people´s behaviour or personality as an indicator of preferred brands. Another possibility is to use core values which describe the attitude or character of a person.

Behavioural Segmentation
Behavioural segmentation is based on the attitudes which consumers have towards a product. In this method, behaviour measures such as knowledge, user status, usage rates, loyalty status or the customers´ willingness to buy can be used to differentiate groups of consumers.
Benefit segmentation is the most widely used characteristic in this field, and it is based on the principal benefits that customers are seeking from a product.[19]

[18] Kotler, 2002, pp. 143-160
[19] Wilson and Gilligan, 2005, p. 338

2.2.2 **Segmentation of business markets**[20]

Many of the variables used in consumer market segmentation can also be applied to business markets. Variables such as geography, benefits sought and user rate are of equal validity for both markets.[21]

As proposed by BONOMA/SHAPIRO, business markets can be segmented by adopting the five different variables demographic, operating variables, purchasing approaches, situational factors and personal characteristics.[22] Figure 2.1 shows the variables and questions that have to be answered in deciding which group of customers a company wants to serve. These business segmentation variables are ordered in declining importance.

Demographic

Industry: Which industries should we serve?
Company size: What size companies should we serve?
Location: What geographical areas should we serve?

Operating Variables

Technology: What customer technologies should we focus on?
User or nonuser status: Should we serve heavy users, medium users, light users, or nonusers?
Customer capabilities: Should we serve customers needing many or fewer services?

Purchasing Approaches

Purchasing-function organization: Should we serve companies with highly centralized or decentralized purchasing organizations?
Power structure: Should we serve companies that are engineering dominated, financially dominated, and so on?
Nature of existing relationships: Should we serve companies with which we have strong relationships or simply go after the most desirable companies?
General purchase policies: Should we serve companies that prefer leasing? Service contracts? Systems purchases? Sealed bidding?
Purchasing criteria: Should we serve companies that are seeking quality? Service? Price?

Situational Factors

Urgency: Should we serve companies that need quick and sudden delivery or service?
Specific application: Should we focus on certain applications of our product rather than all applications?
Size of order: Should we focus on large or small orders?

Personal Characteristics

Buyer–seller similarity: Should we serve companies whose people and values are similar to ours?
Attitudes toward risk: Should we serve risk-taking or risk-avoiding customers?
Loyalty: Should we serve companies that show high loyalty to their suppliers?

Figure 2.1 Major Segmentation Variables for Business Markets[23]

[20] Kotler, 2002, pp. 143-160
[21] Wilson and Gilligan, 2005, p. 338
[22] Bonoma and Shapiro, 1983, pp. 67-74
[23] Kotler, 2002, p. 153, Source: Adapted from Bonoma and Shapiro, 1983

A different approach to segment the market is shown in the market research report related to laboratory equipment. This report reviewed and analysed the market of aqueous analytical instruments. In the study, the market segmentation process was based on key instruments such as pH meters, conductivity meters and other analytical instruments.[24]

A further market study showed that market segmentation based on the applied technology also can be a useful approach.[25] Past experience has shown clearly that also in the analytical instruments industry of Anton Paar the market segmentation method based on product technologies has been applied successfully.[26]

2.3 **Target market selection**[27]

One approach that supports the decision-making process of strategic management is the technology portfolio according to Pfeiffer. The existing and well known portfolio analyses like those from the Boston Consulting Group or the strength-portfolio from McKinsey are also tools for the strategic management of companies. Such portfolio analysis tools are also called market portfolios because they represent the products in a chart and classify them by market share and growth rate. However, they don´t take into account the technology development although this would also be a decisive factor for the competitiveness of companies.[28] The basic assumption of those market portfolios is that product and process technologies develop relatively constantly and therefore must not explicitly be considered.[29] As a result, technology portfolios which consider the aspect of technology development have been established.[30]

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[24] CBS Interactive - Business Wire Publication, 2008, retrieved December 05, 2010, from http://findarticles.com/p/articles/mi_m0EIN/is_2008_Feb_19/ai_n24266258/
[25] Research and Markets, 2008, retrieved December 05, 2010, from http://www.researchandmarkets.com/reports/616391/indian_laboratory_analytical_instruments_markets
[26] G. Murer (personal communication, October 09, 2010), Business Development Manager
[27] Eversheim, 2009, pp. 175-180
[28] Baum, Coenenberg and Günther, 2004, p. 175
[29] Eversheim, 2009, p. 175
[30] Pfeiffer et al., 1982, pp. 77-131

2.3.1 **Technology portfolio**

The main goal of a technology portfolio analysis is to support the decision-making process for strategic technology management.[31] It can help the company to plan and provide sufficient resources for securing their long-term success in business. The portfolio is represented in a two-dimensional chart, where the product function or the process technology is positioned. Based on the positioning of technologies in the portfolio matrix, different strategies for future development activities can be conveyed.[32]

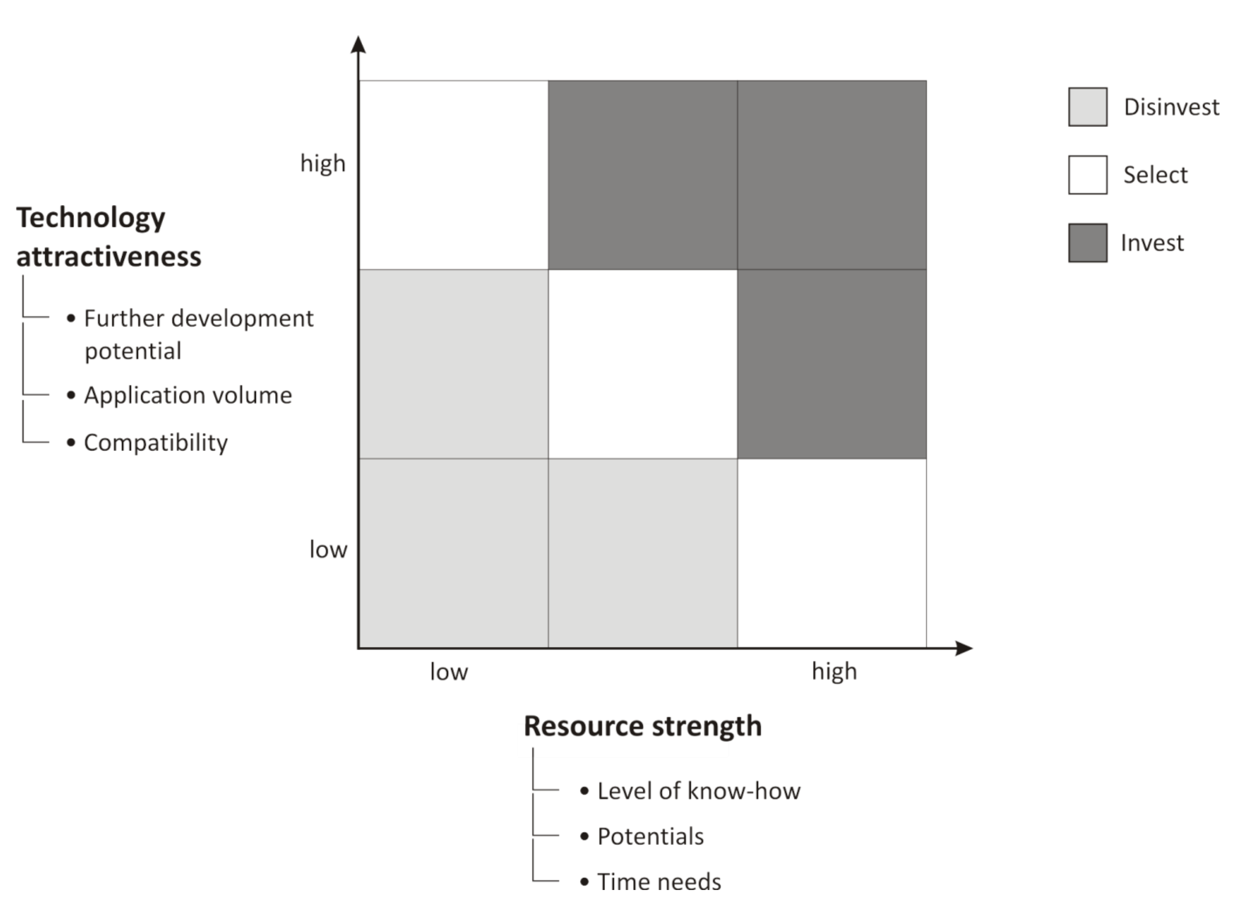

Figure 2.2 Technology portfolio with norm strategies according to Pfeiffer[33]

[31] Eversheim, 2009, p. 180
[32] Baum, Coenenberg and Günther, 2004, p. 217
[33] Redrawn and adapted from Baum, Coenenberg and Günther, 2004, p. 220

2.3.1.1 **Technology attractiveness**[34]

Figure 2.2 shows the technology portfolio in a two-dimensional chart: one axis represents the resource strength which is influenced by the company itself. In contrast, the other axis represents a dimension which is almost entirely influenced by the company´s environment. In the technology portfolio, this dimension is called technology attractiveness. A high attractiveness is assigned to dynamic technologies whereas mature technologies are considered to be more unattractive. The dimension technology attractiveness can be segmented into the following assessment criteria:

- **Further development potential**: To which extent further development of the technology is possible and, linked to this, what are the cost-saving and performance increase potentials.
- **Application volume**: The number of application possibilities and which quantities can be estimated are important criteria for assessing the application volume.
- **Compatibility**: The issue of whether and how synergies can be achieved with existing technologies has to be estimated resulting in the assessment of what impact new technologies can have on current products and processes.

2.3.1.2 **Resource strength**[35]

As an external parameter, the technology attractiveness reflects the sum of all technical and economic advantages which can be gained through a technology.[36] The resource strength on the other hand is an internal factor and represents the knowledge-based human capital and the economic strength for development of technologies. The more resources in the company are available for technology development, the higher the resource strength can be assigned. Furthermore, the resource strength is always to be considered in relation to the competitors.

[34] Baum, Coenenberg and Günther, 2004, pp. 217-219
[35] Baum, Coenenberg and Günther, 2004, p. 217
[36] Eversheim, 2009, p. 180

Following criteria represent the second dimension resource strength:

- **Level of know-how**: Evaluation of the company´s technological know-how especially in contrast to competitors. Having a development advantage in the present might result in competitive advantage in future.

- **Potentials**: The financial strength regarding the technological field is taken into consideration. This criterion also includes material resources as well as human capital regarding staff competence. All this aspects support the company to realize the identified potentials.

- **Time needs**: This criterion evaluates both the company´s capability and the speed of reducing the gap to competitors. And if the company already reached a leading position, the ability to maintain or even to extend its technology leadership is also considered in this part.

2.3.2 **Standard strategies**[37]

Different norm strategies can be derived from the portfolio representation. Each sector is assigned to a standard strategy that in turn provides recommendations for actions. Those recommendations are deducted directly from the position of the technology in the portfolio which is also illustrated in Figure 2.2. The recommendations for actions are mainly focused on the resource management for research and technical development projects and for the production process.
To each field of the technology portfolio matrix, a norm strategy can be allocated:

- **Disinvestment**: Fields which are located in the lower or middle region in both dimensions the technology attractiveness and the resource strength are assigned to a disinvestment strategy. As technologies in this area normally have less potential for further development, research and development activities can be reduced and released resources are available to be used for more attractive technologies. Those fields which are related to disinvestment strategy also have been highlighted (light-grey) in Figure 2.2.

- **Investment**: If both the technology attractiveness and resource strength are high, recommendations can be made to extend current investments into the technology. A dynamic resources allocation aims to maintain the high level of resource strength.

[37] Baum, Coenenberg and Günther, 2004, pp. 220-221

- **Selection**: In the remaining fields recommendations of actions mainly distinguish between two alternatives: high investments if needed or moderate decrease of resource allocations if further investments are not possible. For high technology attractiveness and low resource strength (upper left area) investment decisions and joint development projects with cooperation partners appear useful. In contrast, a complete withdrawal from business can also be a meaningful alternative. In the opposite area with high resource strength but low technology attractiveness, it is possible to decrease the scale of the resources used and focus more on core business.

2.4 Structural industry analysis (Porter’s five forces)[38]

There are a large number of influencing factors in a competitive industry that determine the intensity of competition and the level of profitability. A structured approach can help to assess the competitor’s behaviour as well as the profit potential of an industry.[39] For analysing and classifying the factors of competition, PORTER developed a framework called “The five forces framework”. This framework can be adapted to any manufacturing or services industry and comprises of five main competitive forces: the entry of new competitors, the threat of substitutes, the bargaining power of buyers, the bargaining power of suppliers and the rivalry among the existing firms (see Figure 2.3).

These five forces determine the industry profitability by understanding the five influencing factors in the environment that influence the competitiveness. However, the profitability may vary from industry to industry. HAWAWINI for example showed that industries in the US such as pharmaceuticals or tobacco earn high profit rates whereas in other industries (like the iron and steel industry) only a few companies report attractive returns.[40] The basic assumption is that the industry profitability is depending on the industry structure.[41] By comparing the pharmaceutical industry with the iron industry from the foregoing example, they offer different kind of products and they have also very different industry structures which make one profitable and the other a strong competition with small margins.

[38] Porter, 1985, pp. 1-32
[39] Grant, 2005, pp. 73-74
[40] Hawawini, Subramanian and Verdin, 2003, pp. 1-16
[41] Porter, 1985, pp. 4-5

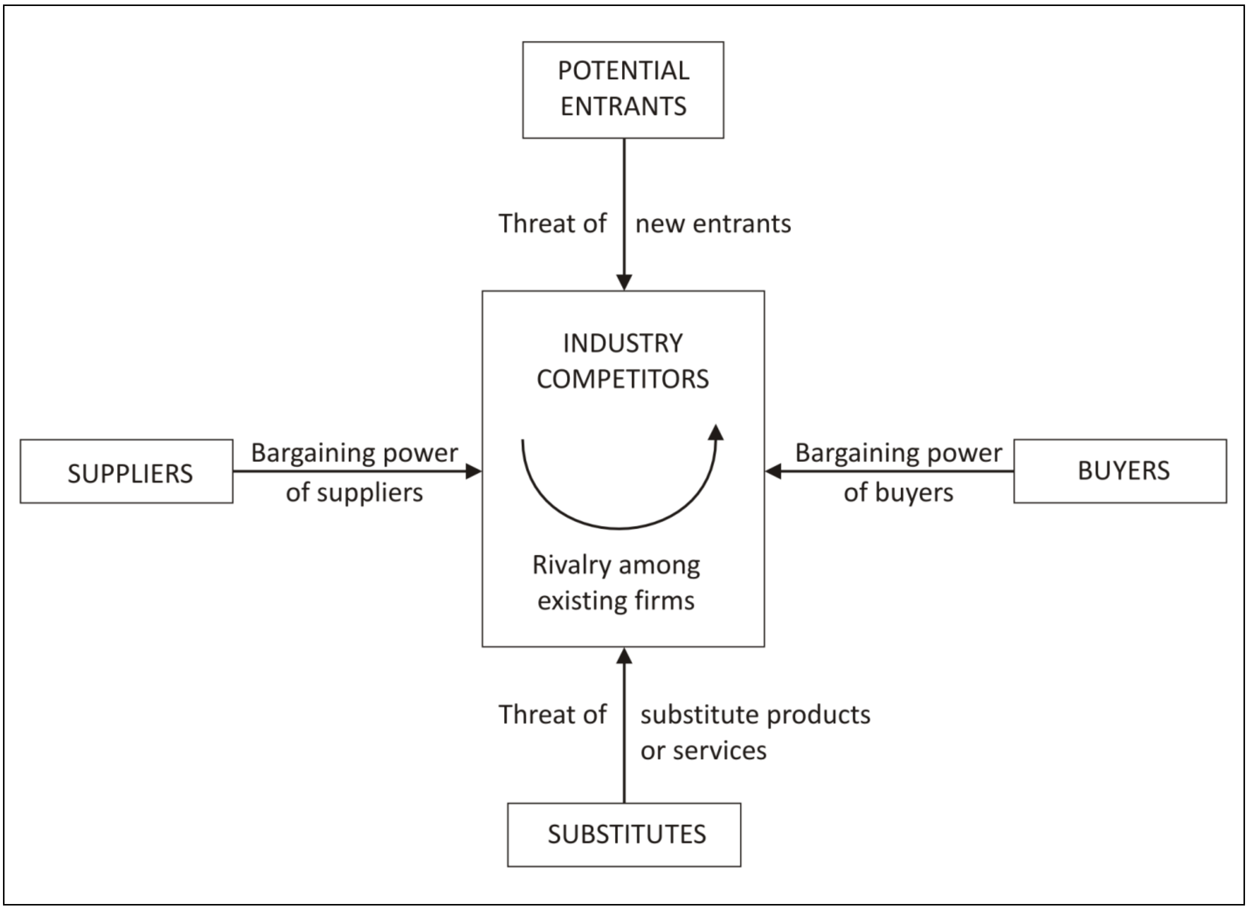

Figure 2.3 The five forces framework of competition by Porter[42]

2.4.1 **Threat of new entry**[43]

If the return on capital in an industry is positive and is expected to sustain on this level or to increase over time, the threat of new firms entering the market is high. New entrants put pressure on prices and costs and desire to gain market share in the new market. It is also possible that big firms may leverage their existing capabilities and financial resources to gain advantage in competition when they want to enter into new markets. In industry, the threat of entry is expected to be low when there are high entry barriers for new entrants. Other sources of entry barriers are economies of scale, access to distribution channels, government policies and customer switching costs.

GRANT stated that high capital requirements of establishing R&D, production and inventories can retard new competitors.[44] In general, entry barriers provide an advantage for established firms over new entrants.

[42] Redrawn from Porter, 1985, p. 5
[43] Porter, 2008, pp. 3-4
[44] Grant, 2005, pp. 75-77

2.4.2 **The power of suppliers**

Companies in industry usually purchase materials, parts, finished products, or services from other companies.[45] This business creates a value for both the customer and the supplier. The share of this value and hence the distribution of profitability for both partner depends on the bargaining power of each side.

PORTER explained that powerful suppliers for example that have a diversified product portfolio do not depend highly on one customer or a specific industry group.[46] The strength of supplier´s bargaining power is also being affected by the proportion of its revenues in an industry. If revenues are allocated to one particular industry, suppliers are keen to earn high rates of profit. Another influencing factor is the importance of the companies´ products for other industry participants. The power of suppliers increases when no substitute products do exist on the market.

2.4.3 **The power of buyers**[47]

Similar to the bargaining power of suppliers, buyers can also exert great influence to the aspect of pricing, product quality, or service quality. Powerful buyers have negotiation leverage relative to industry participants when the purchasing volume generally is high or the order volume relative to the total revenues of the vendor is large. Customers also have bargaining power if the products are standardized and equivalent products are easily available. Switching costs to other vendors as well as the buyer´s price sensitivity are further factors that have influence on the bargaining power of buyers. The greater the influence of a purchased product on the total cost structure, the more sensitive buyers are about the price. In this case, buyers focus strongly on the price and put pressure on lowering the purchasing costs.

2.4.4 **Threat of substitutes**[48]

The availability of substitute products also influences the industry profitability. When a substitute replaces a product or alternative products or technologies emerge, new products may become more attractive for customers and consequently the willingness to pay a higher price for existing products decreases. The threat of substitutes is also high if the switching costs to new products are low. Furthermore, the threat of a substitute is higher if it offers an

[45] Grant, 2005, pp. 81-83
[46] Porter, 2008, pp. 4-5
[47] Porter, 2008, pp. 5-6
[48] Porter, 2008, p. 6

attractive price-performance characteristic. For example, the willingness of consumers to switch between airplane and train in order to travel between two cities strongly depends on the travelling time as well as on the costs for one route.[49]

2.4.5 Rivalry among existing firms[50]

The rivalry among existing firms is another important competitive force that influences the industry profitability over time. There are two main factors to which the profit potential of an industry is depending on the rivalry among companies: The intensity of competition and the basis of competition.

The higher the number of companies competing within a market is the more intense will be the rivalry in an industry or business sector. The intensity of rivalry is also affected by size distribution of each company competing in the same market. If the companies are approximately equal of size and power, the rivalry among the companies appears to be fiercer. Further aspects of competition intensity are exit barriers.
Costs associated with selling a business unit are referred to structural or economic exit barriers. In addition to that, sunk costs which are costs that cannot be recovered from capital investments form barriers to exit. Consequently, costs that arise from a market exit lead companies to stay in declining business and operate at lower profitability than desired.[51]

The strength of rivalry among competitors also reflects the basis of competition. Rivalry in industry often leads to a very hard price competition that also may lower the profitability of the companies. Hereby, the cost structure plays a pivotal role. If the fixed costs of a company are high in relation to the variable costs, pressure is exerted to register deals in order to cover the costs. Companies accept falling prices in the way that revenues contribute to cover at least the fixed costs.
The aspect of spreading fixed costs over greater sales volume is also related to excess of capacity as referred to explanations from GRANT.[52] So if the demand is declining or the excess of capacity results from earlier overinvestments, companies have unused capacity which they want to exploit and utilize better. A decline in prices and falling profitability may be an ensuing result.

[49] Grant, 2005, pp. 73-74
[50] Porter, 2008, pp. 6-7
[51] Harrigan, 1981, pp. 395-412
[52] Grant, 2005, pp. 78-81

2.5 Product development

The economic success of an organisation depends on their ability to understand the needs of the customers and to transform the gained knowledge into new products. The goal hereby is to design new products that meet the customers´ needs. This requires a generic product development process which accumulates the experience and knowledge of many individual organisational units, such as marketing, R&D, or production. ULRICH/EPPINGER defined the term *product development* as a "… set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product." The outcome of a product development process is hereby referred to a physical product that is being sold to the customers. However, a product development process can also be applied to develop software or services.[53]

2.5.1 Product development processes

TROTT found out that a product development process was initially perceived and defined as a four phase concept including idea generation, idea screening, concept development and concept testing. Here, the idea generation phase represented the initial stage and was continued from subsequent phases where ideas were screened and selected. The main target was finally to get out physical products from the process. As the entire product development process resulted to be complex and incurred high costs, attempts have been made to involve different organisational units early in the development process. Manufacturing engineers, design engineers and marketers have been integrated to influence the products while it was still under development.[54]

2.5.2 Definitions of the product development process

Product development process is a generic term for a process which consists of a sequence of steps and includes many activities a company needs to conceptualise, design and finally market a product. This definition according to ULRICH/EPPINGER exists among many others. That is mainly attributable to the high complexity this topic is subjected to.[55]

[53] Ulrich and Eppinger, 2004, p. 2
[54] Trott, 2004, pp. 397-399
[55] Trott, 2004, pp. 397-399

The Product Development and Management Association for example use the term *New Product Development Process (NPD Process)* and defined a process as a set of steps which describe the efforts of a company to convert new ideas into new products or services.[56]

MORGAN/LIKER used a different approach and described a product development system which the automotive manufacturer Toyota had pioneered and applied to develop their products. They investigated why Toyota was so successful on the market some decades ago. The outcome of these research activities was the definition of model which is related to different aspects of product development.[57]

The way MORGAN/LIKER proposed to proceed in product developments has been explained with a model called the Lean Product Development System (LPDS). As shown in Figure 2.4, the model consists of the three subsystems process, people and tools and technology. The main idea of the concept is to integrate people with different functions from different disciplines into the product development system. Furthermore, processes are considered in this model not only as a linear sequence of activities and tasks, but also value creation and waste management are key aspects in this context. The third subsystem includes tools and technologies which can be applied to manage better a product development system. In this part, particular attention is paid to tools which support people in the product development system in terms of problem solving, best practice methods, or learning principles.

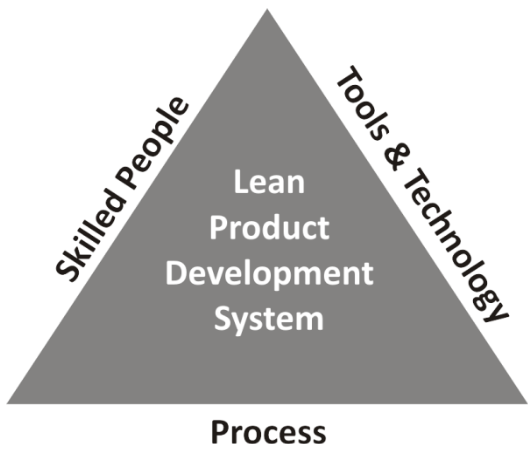

Figure 2.4 Lean Product Development System (LPDS) including three subsystems[58]

[56] New Product Development, 2010, Definition from Product Development and Management Association, retrieved December 06, 2010, from http://www.pdma.org/npd_glossary.cfm
[57] Morgan and Liker, 2006, pp. 3-26
[58] Morgan and Liker, 2006, p. 16

In this work special focus was given to the model of a generic product development process as it was proposed in the study from ULRICH/EPPINGER (see chapter 2.5.3). This is attributable in particular to the fact that this model is a comprehensive approach to understand the complex relationships in product development processes. It is furthermore a practical representation that facilitates the consideration of aspects from different industries.

Another argument in favour of the linear model was that there is a possibility to adapt it for economic evaluations. TROTT observed that linear models have gained attention in the past because a product development process also can be seen as a cash inflow which is followed by a cash outflow.[59]

2.5.3 **The generic product development process**[60]

In chapter 2.5.2, a product development process was already defined as a sequence of steps and activities with the focus to get out a marketable product. These steps include tasks with organisational activities where a set of information has to be organizes and passed to other phases of the process.

The generic product development process, which is shown in Figure 2.1, consists of six phases. The process begins with a planning phase, where market information is taken into account and technology trends are assessed. The output of the planning phase is the project mission statement, which represents the link to the following concept development phase. During the whole project all tasks and activities are aligned to the project mission statement as it includes a detailed description of the project with its goals and hence serves as a clear guidance for the product development team. At the end of the product development process, the product is launched and becomes available on the market.

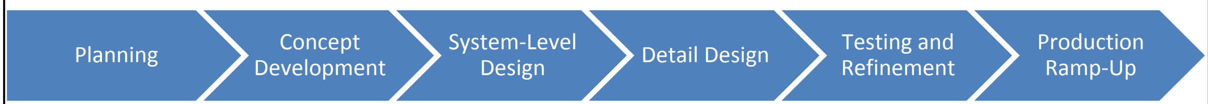

Figure 2.5 Generic product development process[61]

[59] Trott, 2004, pp. 397-399
[60] Ulrich and Eppinger, 2004, pp. 2-21
[61] Redrawn from Ulrich and Eppinger, 2004, p. 9

There are many different ways how an organisation can be structured and processes are used in companies. Every organization applies a process different than all the others because the offered products and services are different in nature, properties and quality too. However, a well-defined development process is beneficial because several aspects like the quality of the end product or continuous improvements of the process can be better assured. The generic development process according to ULRICH/EPPINGER is a structured approach and consists of six phases, which are as follows:

0. **Planning:** Assessments of technology development trends as well as market objectives have to be incorporated into the product design. Before an actual product development project is started, a product plan is needed where the goals and the capabilities of a company are defined (hence the name *phase zero*). The outcome of the planning phase is the project mission statement, which includes a brief description of the product, key business goals, targeted markets and assumptions and constraints.

1. **Concept development:** The customer needs are identified at the beginning of this phase. The resulting information about customer needs is a prerequisite for establishing a product specification and generating product concepts for further development. Various design concepts are also evaluated in this phase in order to be able to select one or more concepts for detailed investigations.

2. **System-level design:** After the selection of one or more concepts that will be focused on, a framework is established that outlines the product architecture and the inner structure of a product. The knowledge about the design and functionality of the product can be used to set up a master plan for the production.

3. **Detail design:** In the detail design phase all parts are specified in terms of its geometry and tolerance and suitable materials are selected for each part. Technical drawings serve for both the production of the parts and its tools as well as for the request for proposal of externally sources components.

4. **Testing and refinement:** Prototypes are of particular importance in this phase as they are used for assembly and functional tests. The first prototypes can differ from the final product in geometry and material properties because rapid prototyping methods may be used to produce initial prototypes. The tests which are performed with prototypes serve for proofing the selected concept and for learning about the functionality and reliability of the product. It is also possible in this phase to identify errors or to integrate changes for the final product.

5. **Production ramp-up**: The production ramp-up phase is the last one in the product development process. Here, the final preparations are made to ramp-up a series production. The aim of this phase is to conclude the development process and deliver the project to production functions. Trainings of labour force are carried out as well as last modifications in the production process are implemented as a final step. The outcome of this phase is a finished product which is ready to be offered on the market.

2.5.4 **Successful product development**[62]

Products that are successful on the market also reflect a successful product development process. To achieve this, it is of great importance to have a lean manufacturing process that transforms raw materials into finished products. This places high demands on the entire manufacturing process in terms of cycle times, quality, flexibility and cost effectiveness. The requirements of a lean manufacturing process are closely related to those of a product development process. The defining attributes of a successful product development are as follows:

1. Product development costs
2. Product quality
3. Product development time
4. Development of know-how

2.5.4.1 **Product development costs**

The product costs comprise the production costs as well as the total development costs. As being a decisive factor in the customers´ decision to buy, the selling price is determined mainly by the product costs. The selling price, in turn, influences the profitability of the company. So the company´s profitability depends on the structure of fixed and variable costs.

Fixed costs such as administrative salary, rent, or depreciation are referred to costs that do not change with the output quantity. In contrast, variable costs such as direct labour costs or material costs vary in proportion to changes of the output.[63]

[62] Mital et al., 2008, pp. 17-36
[63] Hansen, Mowen and Guan, 2007, pp. 51-54

Costs which incur in the research and development phase also determine the profitability. These development costs have to be covered in order to get a successful product. Figure 2.6 shows the cumulative cash flow through the development phases. In early phases in which research and development activities and prototype tests are made, there is no in-flow of cash from sales. The cash in-flow coming from profitable sales turns the negative project progress into positive. A product becomes profitable after the entire development costs are fully covered.

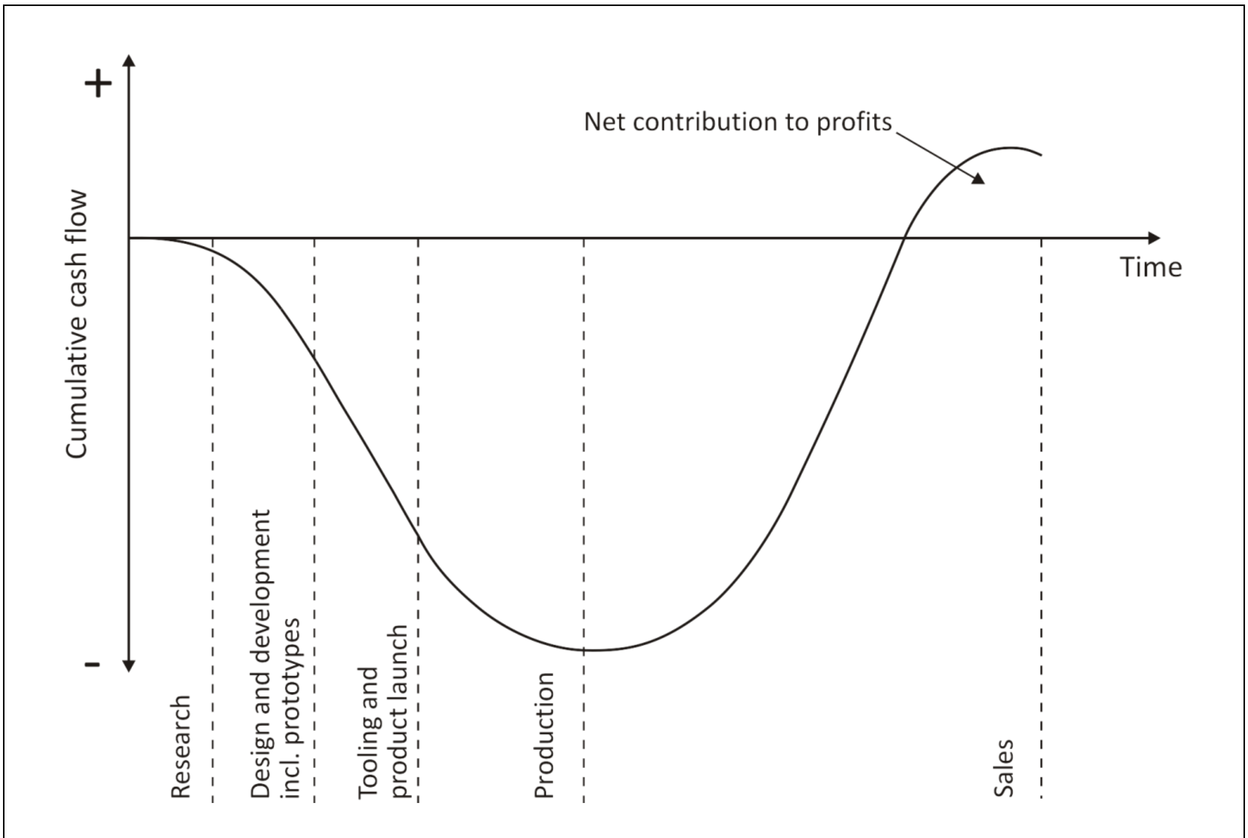

Figure 2.6 Typical cash flow for a successful new product[64]

2.5.4.2 **Product quality**

The quality of products is another dimension used to assess the performance of product development efforts. The price that customers are willing to pay is determined by the quality of the product. Furthermore, product quality is also reflected in market share a product is able to gain.

[64] Adopted from Trott, 2004, p. 358

2.5.4.3 **Product development time**

ULRICH/EPPINGER described that a short product development time reflects the capability of a company to react on changing situations on the competing market. The development time determines when products become profitable. It further determines how quickly the product development efforts receive an economic return. The shorter the development time of a product is the more time is left to capture significant market share.[65]

2.5.4.4 **Development of know-how**

Innovative products, which are successful on the market, and also the continuation of launching new products on the market successfully, reflect the knowledge a company gained with product development projects.[66] According to ULRICH/EPPINGER, experience and knowledge about product development processes can be used to make future projects more efficiently.[67]

2.5.5 **Variations in the product development process**[68]

The generic product development process, which was described in chapter 2.5.3, can also be seen as a market-pull strategy: customer request for products or solutions and companies begin product development in order to satisfy the demand.

MARTIN stated that a development process which is initiated in response to identified market needs reflects the market-pull strategy. The market "pulls" the demand through R&D functions, production and marketing as shown in Figure 2.7.[69]

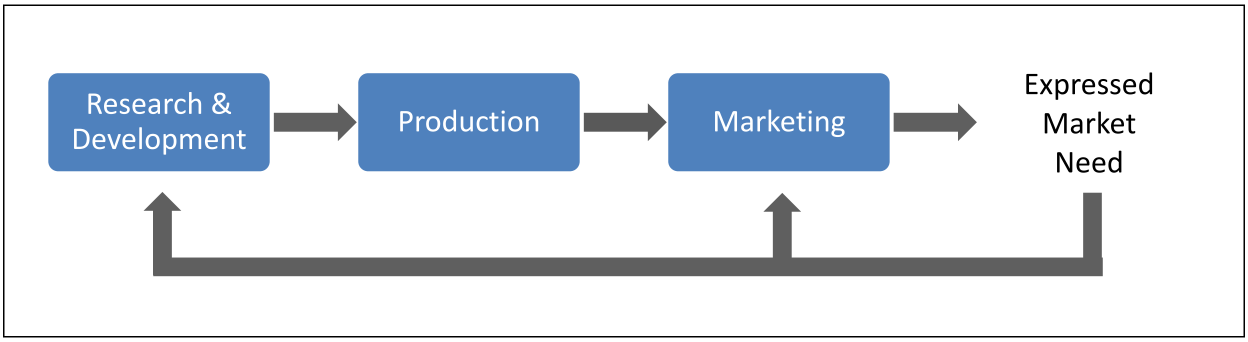

Figure 2.7 Market-pull sequence[70]

[65] Ulrich and Eppinger, 2004, pp. 2-3
[66] Mital et al., 2008, pp. 17-36
[67] Ulrich and Eppinger, 2004, pp. 2-3
[68] Ulrich and Eppinger, 2004, pp. 18-21
[69] Martin, 1994, pp. 43-47

However, product development processes don´t look the same in all companies as each company has different products as well as follow different corporate principles and guidelines. In addition to the generic product development process that reflects the market-pull principle, other common variants are as follows:

- Technology-Push Products
- Platform Products
- Process-Intensive Products
- Customized Products
- High-Risk Products
- Quick-Build Products
- Complex Systems

2.5.5.1 **Technology-Push Products**

In developing technology-push products, technological advances and new inventions trigger a decision to develop new products. The company first begins to develop new products which are based on the new technologies and looks for a target market and application possibilities afterwards. An example of a technology-push products are Gore-Tex clothes.

MARTIN describes a technology-push strategy in the way that the a new invention is "pushed" through the company´s R&D, production and sales functions onto the market, regardless if the market has demanded the products before or not.[71] A sequence of technology-push interactions is also shown in Figure 2.8.

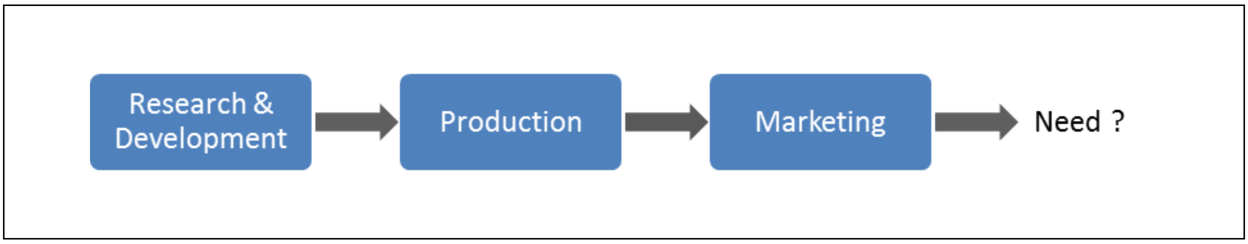

Figure 2.8 Technology-push sequence[72]

[70] Martin, 1994, p. 44
[71] Martin, 1994, pp. 43-47
[72] Adopted from Martin, 1994, p. 44

2.5.5.2 **Platform Products**

New products built on existing technology platforms have certain characteristics that are advantageous over those products which are developed from completely new technologies: The efforts needed to develop a new product are lower and the costs related to the production can be shared across several products.

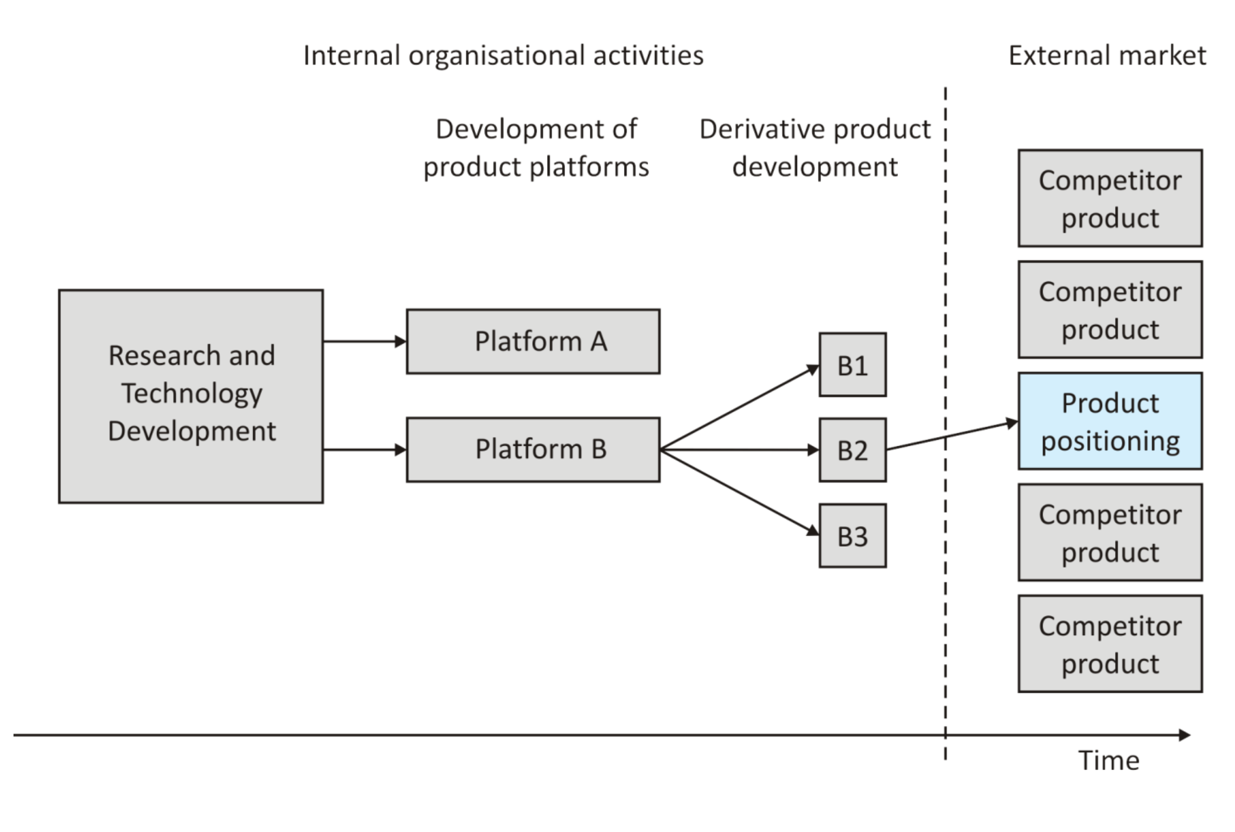

Figure 2.9 Schematic illustration of platform development and a derived product family[73]

The difference to technology-push products hereby is that the technology used in platform products has already demonstrated on the market its utility for customers. Figure 2.9 shows how R&D functions in companies develop platform technologies which are the basis for a whole product family.

In automotive industry, for example, platform products help to share production processes whereas at the same time customer needs can be addressed with different car models. MUFFATTO/ROVEDA pointed out in their study that one car structure regarding frame, suspensions, engine and powertrain is used in different models of a unique family.[74]

[73] Redrawn and adapted from Trott, 2004, p.358
[74] Muffatto and Roveda, 2000, pp. 617-625

2.5.5.3 **Process-Intensive Products**

Characteristics of process-intensive products are particularly constrained by the production process. As the production process has strong influences on the properties of the products, the design of the product and the design of the production process are assigned to be correlated with each other. For process-intensive products, either both the product and the production process are developed simultaneously, or the process for making the product is chosen before the product is being designed. Examples of process-intensive products are semiconductors, foods and chemicals.

2.5.5.4 **Customized Products**

Customized products underline the companies´ ability to design special products to meet the customer´s demand. When a customer requests a new product, the company begins to design a tailored product in a structured development process. The new products are usually slight variations of existing configurations. The development process of customized products includes the specification of product properties such as physical dimension or material properties. Motors, switches and batteries are examples of customized products.

2.5.5.5 **High-Risk Products**

During a product development process there are many issues that can prevent the success of development strategy. Product development is a process that involves many risks, including technical risks and market risks. That is why managing of risks especially during development of high-risk products is becoming more important. High-tech products are subject to risks and uncertainties related to proper function of the product (technical risk) or to customer acceptance (market risk). In order to manage those risks, the generic product development process is adapted by taking measures to address the biggest risks early in the process. This includes testing activities in early stages of a product development for the evaluation of customer acceptance of the new product. In case of high technical uncertainties and risks prototypes or working models which are also built in earlier development stages can help to test key features and functionalities of the products.

GOODMAN et al. showed at the example of Intel how risk management is integrated in semiconductor industry. They describe how a risk management process was developed and a central risk database that helps to identify, assess and deal with risks during product development had been deployed.[75]

[75] Goodman et al., 2007, pp. 105-108

2.5.5.6 **Quick-Build Products**

In developing quick-build products, several iteration steps are made during the development process where prototypes are built and functional tests are conducted. This allows the development team to take advantage of gained experience from the test results and learn how further development steps can be proceeded. With repeated cycles of design, build and test activities the involved team can achieve a more flexible product development process. It is also possible to involve customers in testing phases of the product in order to enhance customer acceptance.

Software and many electronics products are examples where many detail design and testing phases are repeated. The company Paterson Technology explained the strategy that was applied during the development of the Microsoft´s first operating system MS-DOS. They describe how a very short development phase resulted in a product that included the basic functionalities by applying a quick-and-dirty approach.[76]

2.5.5.7 **Complex Systems**

Complex systems are usually decomposed into several subsystems and many components. Different teams then are able to develop the components, mostly independently of each other. After having completed the development tasks, an integration of all components into the subsystem and subsequently into the overall system is needed. Examples of developing complex systems include air aircraft construction and jet engine design.

[76] Paterson Technology, retrieved December 05, 2010, from http://www.patersontech.com/Dos/Byte/History.html

3 Principles and Applications of Thermal Analysis

3.1 Definition of thermal analysis

The term *Thermal Analysis* comprises a number of measuring techniques that have one feature in common: they measure the change of material properties in response to temperature changes during a heating, cooling or an isothermal phase. ROUQUEROL tried to find a definition which is simple and formulated in a general way. The definition of “Thermal Analysis” presented by ROUQUEROL also has been approved to the International Confederation for Thermal Analysis and Calorimetry (ICTA), and is as follows:[77]

"Thermal analysis (TA) is the study of the relationship between a sample property and its temperature as the sample is heated or cooled in a controlled manner."

According to MENCZEL/PRIME/GALLAGHER, the most popular techniques among all thermal analysis methods are differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), thermomechanical analysis (TMA), dynamic mechanical analysis (DMA), dielectric analysis (DEA) and micro/nano - thermal analysis (µ/n - TA). Table 3.1 also shows the classification of more common techniques by physical property measured.[78]

Table 3.1 Most important methods and techniques of thermal analysis[79]

General Method	Acronym	Property Measured
Differential scanning calorimetry	DSC	ΔT, differential power input
Differential thermal analysis	DTA	ΔT
Thermogravimetry or Thermogravimetric analysis	TG or TGA	Mass
Thermomechanical analysis, Thermodilatometry	TMA, TD	Length or volume
Dynamic mechanical analysis	DMA	Viscoelastic properties
Dielectric analysis	DEA	Dielectric properties
Micro/Nano - thermal analysis	µ/n - TA	Penetration, ΔT

[77] Rouquerol, 2008, pp. 13-54
[78] Menczel, Prime and Gallagher, 2008, pp. 1-12
[79] Menczel, Prime and Gallagher, 2008, p. 2

There are many more methods which are gaining increased importance, such as evolved gas analysis (EGA)[80] or thermo-optical analysis (TOA)[81], among others. However, it seemed appropriate to set a focus in this work, as it was also the scope of the company to concentrate only on the most common thermal analysis methods, which are as follows:

- Differential scanning calorimetry (DSC)
- Thermogravimetric analysis (TGA)
- Thermomechanical analysis (TMA)
- Dynamic mechanical analysis (DMA)

3.2 Overview of thermal analysis principles[82]

This chapter will describe these thermal analysis methods more in detail which helps to answer open questions by presenting an overview of the most common used methods. I want to highlight the basic principle, the setup of a dedicated instrument and important aspects of every method. Hence, this chapter provides an overview of those four thermal analysis methods, to which the complete work is referred to.

3.2.1 Differential scanning calorimetry

Differential scanning calorimetry (DSC) is the most common thermal analysis technique. According to MENCZEL et al., the DSC method is used in many applications including polymer and pharmaceutical fields as well as inorganic and organic chemistry.[83] The basic principle of DSC is that the heat flow into a sample is measured as a function of temperature or time. The approach involves the application of a controlled temperature program to a sample and a reference in order to determine the temperature or energy related to a range of thermal events including melting or crystallization processes, measurement of glass transitions and many other thermal parameters of chemical reactions. READING/CRAIG explained that among the three possible temperature profiles heating, cooling, or isothermal program, the heating profile is the most widely used approach.[84]

[80] Brown, 2001, pp. 139-156
[81] Mucha, 1989, pp. 876-880
[82] Gabott, 2008, pp. 1-163
[83] Menczel et al., 2009, pp. 7-240
[84] Reading and Craig, 2007, pp. 1-22

Within the differential scanning calorimetry method two techniques can be differentiated:

- Heat flux DSC
- Power compensation DSC

Heat flux DSC

Heat flux DSC involves one single furnace where both the sample and the reference together are heated up or cooled down in a controlled temperature program. During the heating or cooling phase the temperature of both probes is measured continuously. Figure 3.1 demonstrates where temperature sensors for each of the sample and the reference pans are located. The main parameter, which is determined during measurement, is the temperature difference between sample and reference. The temperature difference indicates the effect of phase transition of the sample. As an example, the process of melting can be considered. During melting of a crystal the temperature remains at the melting point despite a constant heat flow reaches the sample. Consequently the temperature of the sample falls behind that of the reference as the heat is absorbed by the sample material during endothermic transition. By recording the temperature difference, DSC instruments convert these values into a heat flow equivalent, which is displayed as a function of temperature or time representing the result of the measurement.

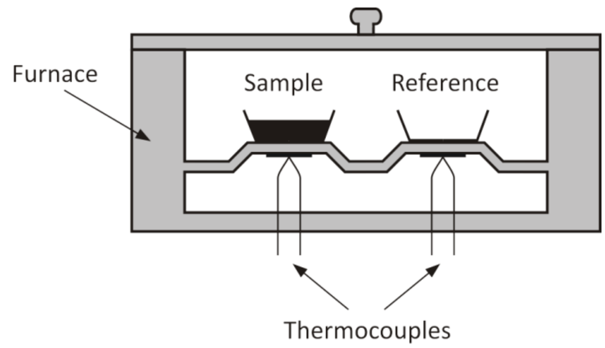

Figure 3.1 Schematic of a heat flux DSC[85]

Power compensation DSC

In power compensation DSC, the measurement system consists of two separate furnaces, one for the sample and a second for the reference. Both are controlled by a temperature program where heating up or cooling down phases are applied. During one heating (or cooling) rate, the difference in electrical power to maintain both measuring cells on the same temperature level is measured.

[85] Redrawn and adapted from Ehrenstein, Riedel and Trawiel, 2003, p. 3

The difference in energy flowing into the sample furnace compared to the reference furnace is displayed as a function of temperature or time. One type of instrument with power compensation DSC is represented schematically in Figure 3.2.

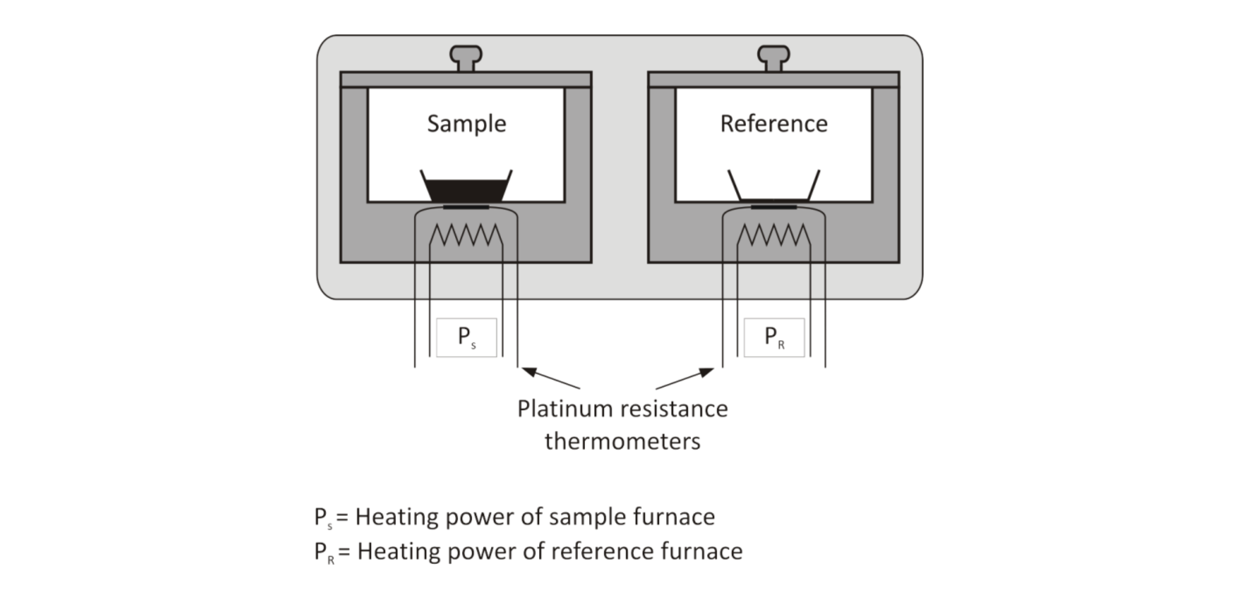

Figure 3.2 Schematic of a power compensation DSC[86]

3.2.2 **Thermogravimetric analysis**

Thermogravimetric analysis (TGA) is a technique where the mass of a substance is measured as a function of temperature or time. The sample is usually heated up following a controlled temperature profile in a controlled atmosphere. The method is characterized by exposing the sample to an atmosphere which can be inert, oxidizing, or reducing. Mass changes may occur in both ways, either the sample loses material when for example volatile constituents are evaporated, or it gains mass like in humidity controlled experiments where water is absorbed.

TGA is a common used method in research and industry to study characteristics of materials such as polymers and how diverse reactions occur on heating substances in a controlled atmosphere. In pharmaceutical science this method is used to investigate the dehydration behaviour and the quantity of water lost from solid drugs. Furthermore, TGA methods have been employed in many studies including decompositions of inorganic and organic compounds, thermal reactions of natural materials such as coal or wood and mass loss measurement of foodstuff.[87]

[86] Redrawn and adapted from Ehrenstein, Riedel and Trawiel, 2003, p. 4
[87] Galawey and Craig, 2007, pp. 139-192

Measuring principle of the TGA method

In a TGA instrument, the central part is the thermobalance which detects mass changes as a function of temperature or time. As shown in Figure 3.3, a compensation system is used to compensate offset changes in reactant mass. With the combination of thermobalance and compensation system the position of the sample remains the same when mass changes occur. The main characteristic of all types of TGA instruments is that the sample is exposed to a temperature controlled zone. However, several design variations of thermobalances, involving different relative positions of the components do exist. The three standard sample and furnace positions relative to the thermobalance include top-loading, side-loading and bottom loading configuration, whereas the side-loading or horizontal arrangement is represented in Figure 3.3.

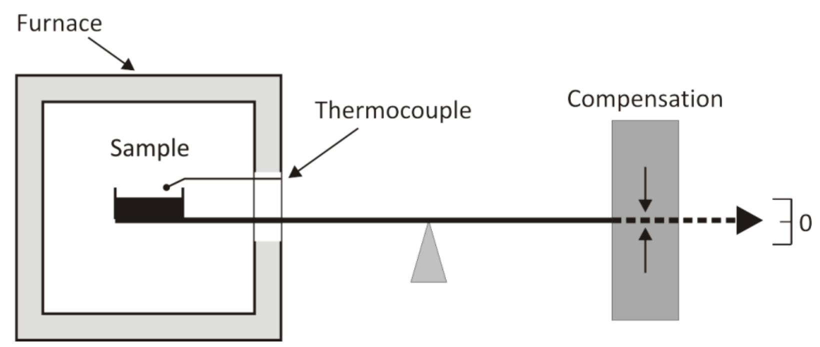

Figure 3.3 Schematic of TGA principle with horizontal thermobalance[88]

3.2.3 Thermomechanical analysis

Thermomechanical analysis (TMA) measures changes in length or volume of the sample under static load, variable load, or with zero load. The most important applications of TMA measurements are determination of the coefficient of linear thermal expansion and the glass transition temperature. For the measurement of thermal expansion coefficient, a small force must be applied to keep the probe in contact with the sample. Further application options are stress relaxation, creep and volume change tests. TMA is a useful thermal analysis technique for the characterization of polymeric materials. Properties of materials such glass transition and melting temperature as well as Young´s modulus of films and fibers can be investigated with this method.[89]

[88] Adapted from Ehrenstein, Riedel and Trawiel, 2003, p. 150
[89] Bair et al., 2009, pp. 319-386

Measuring principle of the TMA method

The sample with cylindrical or rectangular shape is positioned in a furnace and heated up with a controlled temperature profile. A quartz probe, which keeps contact with the sample, with integrated displacement measuring system detects changes in volume of the sample. The temperature of the sample is measured with thermocouples, which are located very close to the sample. Figure 3.4 illustrates a schematic diagram of a vertical design TMA instrument. However, a wide variety of instruments with different designs are available on the market.[90]

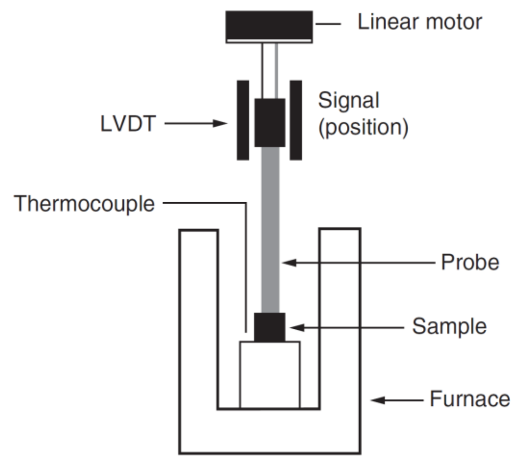

Figure 3.4 Schematic of a TMA instrument with vertical design[91]

3.2.4 **Dynamic mechanical analysis**

Dynamic mechanical analysis (DMA) involves applying a periodic strain on a sample and measuring the resulting stress, or equivalently, applying a periodic stress on a sample and measuring the resultant strain response. Figure 3.5 shows the basic principle of DMA operations where the strain and stress are out of phase. A DMA measurement typically includes the amplitude of the signals as well as the phase difference between them.[92]

[90] Ehrenstein, Riedel and Trawiel, 2003, pp. 185-223
[91] Bair et al., 2009, p. 327
[92] Chartoff, Menczel and Dillmann, 2009, pp. 387-496

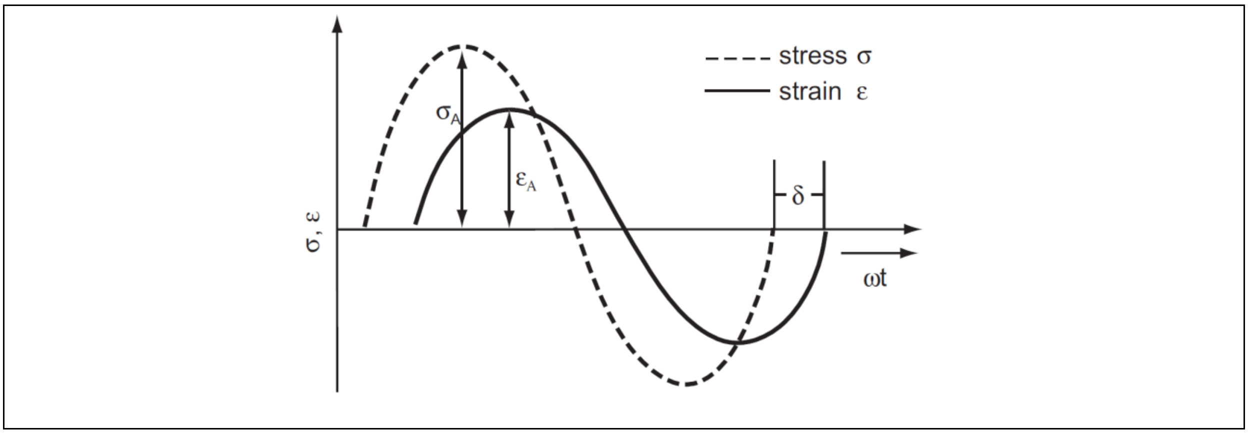

Figure 3.5 Sinusoidal oscillation of stress signal and response of strain signal of a linear-viscoelastic material[93]

According to DUNCAN, the analysis of polymeric materials is the main area where DMA is being used. Furthermore, DMA also has been widely employed for studying the molecular structure of materials. In the food and bioscience sector, which represents another field of DMA applications, glass transition temperatures of materials are determined and the similarity of samples are checked. A more specialized application field of DMA is the derivation of engineering data. Here, material data including the determination of modulus and damping factor are generated over a wide range of frequency and temperature. This is of special interest for producers of acoustic damping materials or designers of critical components. In Figure 3.6, the main fields of applications of DMA instruments are shown in a diagram.[94]

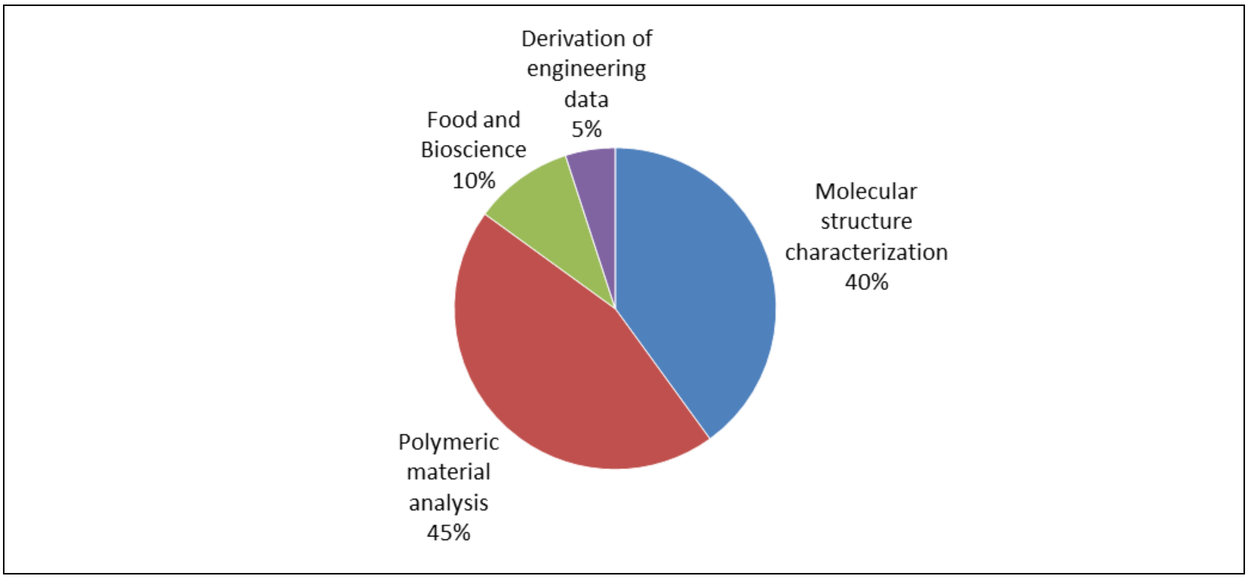

Figure 3.6 The use of DMA divided into four main areas[95]

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[93] Ehrenstein, Riedel and Trawiel, 2003, p. 255
[94] Duncan, 2008, pp. 119-163
[95] Own illustration, Data aggregated from Duncan, 2008, pp. 119-163

Essential information about the complex stiffness of a material can be obtained with DMA instruments. The complex stiffness is converted to complex modulus, which represents the main parameter of the DMA principle. The complex modulus is a characteristic property of viscoelastic materials. Mathematical relationships between moduli used in DMA are shown in Figure 3.7.[96]

The complex modulus *E** may be divided into real and imaginary components. For viscoelastic materials, the storage or real modulus *E'* and the loss or imaginary modulus *E''* are of particular importance. The storage modulus *E'* represents the stiffness of a viscoelastic material and the loss modulus *E''* represents the proportion of energy which is dissipated during one cycle.[97]
Taking into account δ as the phase difference between dynamic stress and dynamic strain (see Figure 1.1), another important quantity can be defined. The ratio between loss modulus and storage modulus may be expressed by *tan δ*, which is known as the damping factor.[98]

$$E^* = E' + iE''$$

$$E' = \frac{\sigma_0}{\varepsilon_0}\cos(\delta)$$

$$E'' = \frac{\sigma_0}{\varepsilon_0}\sin(\delta)$$

$$\frac{E''}{E'} = \frac{\sin(\delta)}{\cos(\delta)} = \tan(\delta)$$

Figure 3.7 Mathematical relationships for complex modulus *E**, storage modulus *E'*, loss modulus *E''* and damping factor *tan δ*[99]

Measuring principle of the DMA method
DMA instruments operate in a constant amplitude mode with variable frequency. The defined amplitude of mechanical load is related either to a stress or deformation amplitude. The sample is clamped at both ends so that a periodic signal can be applied. A typical DMA instrument with vertical design is schematically shown in Figure 3.8.[100]

[96] Duncan, 2008, pp. 119-163
[97] Chartoff, Menczel and Dillmann, 2009, pp. 387-496
[98] Duncan, 2008, pp. 119-163
[99] Chartoff, Menczel and Dillmann, 2009, pp. 387-496
[100] Ehrenstein, Riedel and Trawiel, 2003, pp. 255-323

The most important factor in obtaining good measurement results is choosing the best geometry of the sample. In order to find an appropriate geometry, the value range of the material´s modulus has to be known or estimated in advance. A schematic of available sample geometries is shown in Figure 3.9.[101]

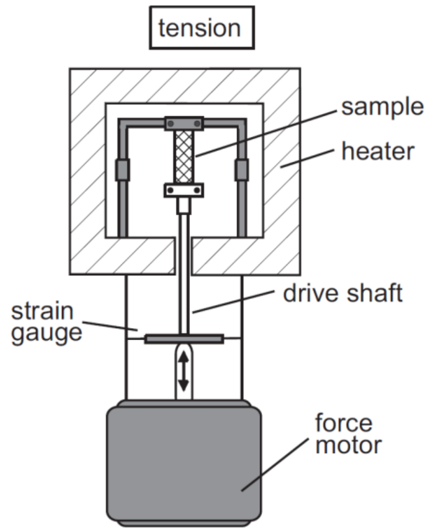

Figure 3.8 Schematic of a DMA instrument with vertical design[102]

Clamped bending is generally used for sample bars as it is an easy handling mode and covers a wide modulus range. For materials having a high modulus value the choice of three-point bending is recommended. High-modulus samples where three-point bending is usually applied are for example fibre reinforces composites or brittle samples such as inorganic glass and ceramics. Tension mode is generally suitable for film samples and fibres with low sample thickness - samples with a thickness lower than 0,02 mm are also possible. Materials representing a low modulus range such as rubbers and gels are usually measured in shear mode. Compression mode can be used to determine for example the transition temperature of powders. Foams with its typical low modulus values are also ideally suited for tests conducted in compression mode.[103]

[101] Duncan, 2008, pp. 119-163
[102] Ehrenstein, Riedel and Trawiel, 2003, p. 261
[103] Duncan, 2008, pp. 119-163

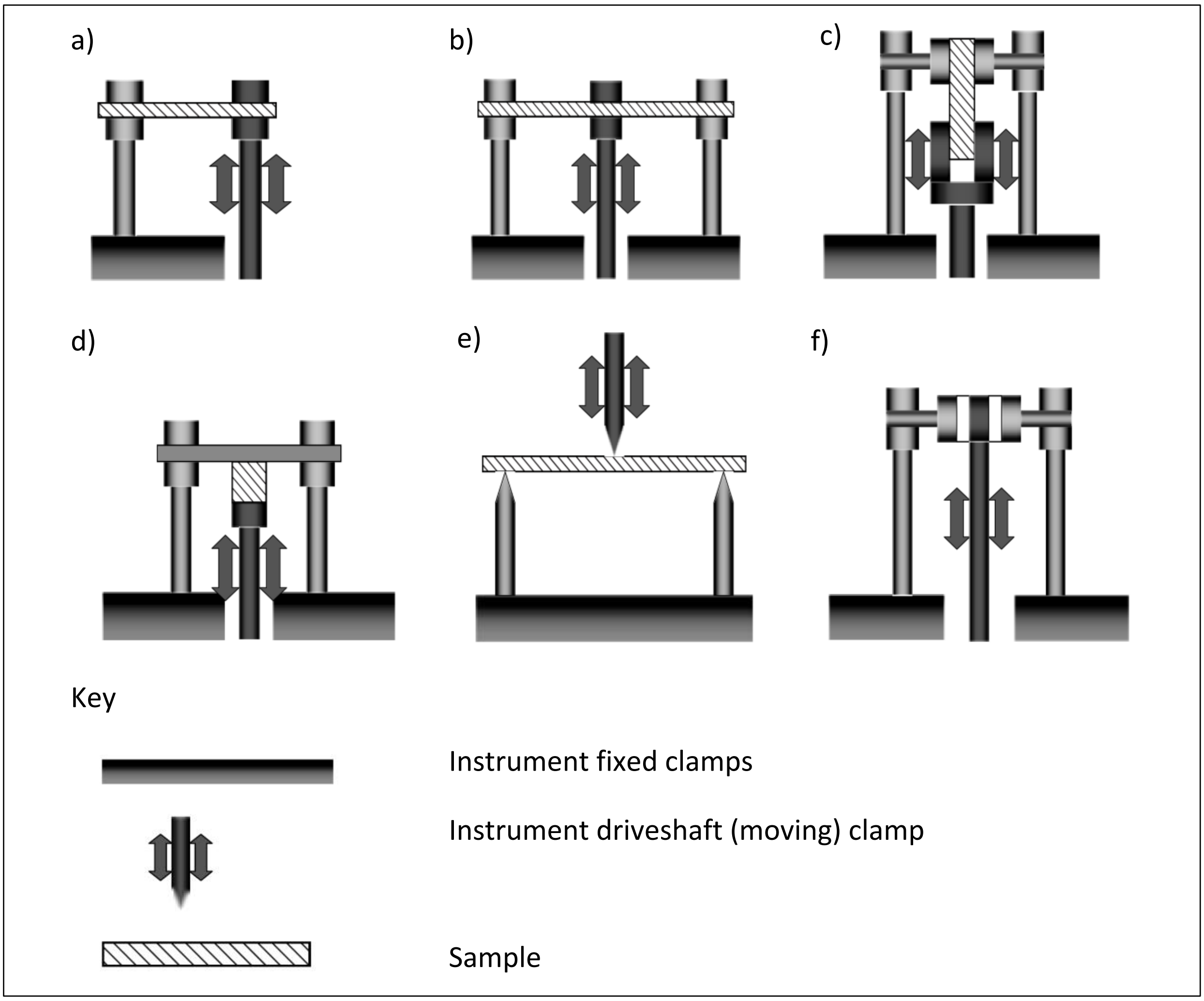

Figure 3.9 Schematic of available sample geometries. (a) single cantilever bending; (b) dual cantilever bending; (c) tension; (d) compression; (e) three-point bending; (f) shear[104]

3.3 Applications of thermal analysis[105]

This section shows different application possibilities of thermal analysis. Data and information which have been collected for this topic relate on many different sources. These sources are in particular publications in journals and books, online articles and application reports from thermal analysis companies. All fields of applications which have been identified within this thesis are explained in the following section, whereas the most important thermal analysis methods are correlated to each single application field.

[104] Adapted from Duncan, 2008, p.132
[105] Gabbott, 2008, pp. 164-446

3.3.1 **Application to thermoplastics and rubbers**

Thermal analysis provides valuable information on polymeric materials regarding the composition and physiochemical properties of thermoplastics and rubber materials. Due to the large macromolecules polymers are comprised of, they have broad melting points, molecular weight distributions and glass transition temperatures. In the case of both thermoplastics and rubbers, degradation can occur due to harmful influences such as ultraviolet light, heat, radiation and specific environmental chemicals such as ozone. Or in the case of rubbers, curing (also known as vulcanisation) is employed to achieve satisfactory products. To study these properties and also many other influencing factors, thermal analysis is ideally suited to enable analysis of polymeric materials. Some of the more important properties of thermoplastics and rubbers that can be measured by TA techniques are listed below:

- Chemical composition
- Cross-link density and cross-linking reactions
- Thermal conductivity
- Glass transition temperatures
- Crystalline melting temperatures
- Heats of reaction (e.g., curing or degradation)
- The influence of additives and thermal history (e.g., processing temperature)

Many different analytical techniques can be used to analyse thermoplastics and rubbers, but the common used techniques TGA, DMA and DSC will be considered more in detail in this chapter.

TGA

Thermogravimetric analysis measurements are mainly used to determine the composition of polymer products and precursors, but can also be used to measure thermal stability and study the effects that additives such as antidegradants can have.

In the analysis of polymers, temperatures from ambient to 1000°C can be used in either oxidising (e.g., oxygen or air) or non-oxidising (e.g., nitrogen or helium) atmospheres.

DMA

Unlike TMA, DMA can analyse properties of polymers as a function of temperature as they are deformed under a periodic stress. It is the most sensitive thermal technique for the determination of the glass transition temperature (T_g) of plastics and rubbers. DMA is also able to provide information about the modulus (stiffness), damping (energy dissipation) and viscoelasticity of polymers.

DSC

DSC is a very useful tool for providing information to identify unknown plastic samples, also in combination other techniques such as infrared spectroscopy. Although DSC is less sensitive to determine the glass transition temperature (T_g) than DMA, it is also used to determine the T_g of rubbers and plastics. However, DSC also has got advantages: for instance no specific sample geometry is required and the amount of material required to perform an analysis is much more less.

3.3.2 Thermal analysis of pharmaceuticals

SAUNDERS stated that one range of equipment that is commonly used in pharmaceutical drug development is that of thermal analysis. This field of investigation helps to understand the physical properties of drug substances, drug substance/excipient interactions and final drug product stability.[106]

DSC and TGA, which are two important thermal analysis methods in the field of pharmaceutical drug development, are shortly explained in the following section.

DSC

According to READING/CRAIG, DSC is the most widespread used method within the pharmaceutical field.[107] One important parameter that can be obtained from a DSC experiment is the determination of the melting point of a test compound. For the pharmaceutical industry it is furthermore of vital importance to investigate the polymorphic behaviour of drugs in terms of its dissolubility and bioavailability. The term *bioavailability* refers to absorption of drugs depending on its route of administration.[108]

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[106] Saunders, 2008, pp. 286-329
[107] Reading and Craig, 2007 pp. 1-22
[108] Bioavailability, 2007, Definition from The Merck Manual, retrieved December 05, 2010 from http://www.merckmanuals.com/professional/sec20/ch303/ch303c.html

SAUNDERS also explained how DSC curves may be obtained when examining solvates and hydrates in pharmaceutical drugs. According to LOHANI/GRANT, crystals which consist of distinctive molecules are formed during crystallization from solutions. A solvate is a crystalline molecular compound in which molecules of the solvent are incorporated into the lattice of the parent substance. When water is used as a solvent, the solvate is also called hydrate. The solubility and the dissolution rate of a solvate influence the bioavailability of drugs.[109]

TGA[110]

TGA is a simple and conceptually accessible means of characterizing pharmaceutical samples. However, complex analyses are needed in order to take full advantage of the possibilities offered by TGA. The most common use of TGA in pharmaceutical fields is the characterization of hydrates, where the water content within the solid can be estimated. Furthermore, the method may be used to:

- Assess glassy materials in terms of measuring plasticizer levels such as water. Hereby, TGA is a useful complementary technique to DSC.
- Study both conventional and controlled release dosage forms, as a means of understanding solvent binding.
- Obtain a more detailed analysis of the kinetics of dehydration and the nature of the drug or excipient–water interactions.

3.3.3 **Thermal methods in the study of foods and food ingredients**[111]

Properties of foods and food ingredients and how they change to variations in temperature are important in understanding food production processes and variation in food quality.
A wide range of physical properties of foods can be studied by using thermal analysis methods. As an example, amorphous states of pastes and viscous liquids, such as starch solutions in sauces or sugar syrups are considered in this field. Furthermore, hard solids like dried extrudates of starch and gelatine are of interest in food science.

Concentrated food systems (low-moisture and frozen foods) are often in a non-equilibrium state which results in formation amorphous, non-crystalline structures. There are also many materials which are present in the crystalline form and expose melting behaviour ranging from recrystallization of gelatinized starch to the melting and crystallization of sugars and fats.

[109] Lohani and Grant, 2006, pp.37-40
[110] Bottom, 2008, pp. 87-118
[111] Roos, 2008, pp. 197-203

Low-temperature behaviour of food is another area where research activities are carried out. This is relevant to ice cream, frozen desserts and ready meals where ice-formation, recrystallization and enzymatic reactions can be observed.

A variety of different analytical techniques can be used to monitor changes in the physical properties of food components. However, TGA, DSC and DMA have become common and important analytical methods in physiochemical characterization of foods.

3.3.4 **Application to biomaterials**

Biomaterial can be defined as “any nondrug substance that can be used as a system or part of a system to treat, enhance, or replace any tissue, organ, or function of the body”.[112] Any material can be a biomaterial as long as it fulfils the medical and surgical requirements, and therefore a wide range of materials such as metals, ceramics, glasses, polymers and composites are applicable for the use in the human body. Various types of application where biomaterials are used in medical products and devices are shown in Figure 3.10. Polymers can have a wide range of properties and therefore constitute the largest group of biomaterials.

Thermal characterisations will provide general information of biomaterials in terms of stability, shrinkage, expansion, effect of sterilisation methods, insulation and storage. In addition, the thermal behaviour of a material forms an important part of characterising a material’s properties which are also related to its clinical performance. For example, biomaterials will need to be sterilized to reduce the risk of infection before they are used in clinical environment.

[112] Morris, 1992, p. 262

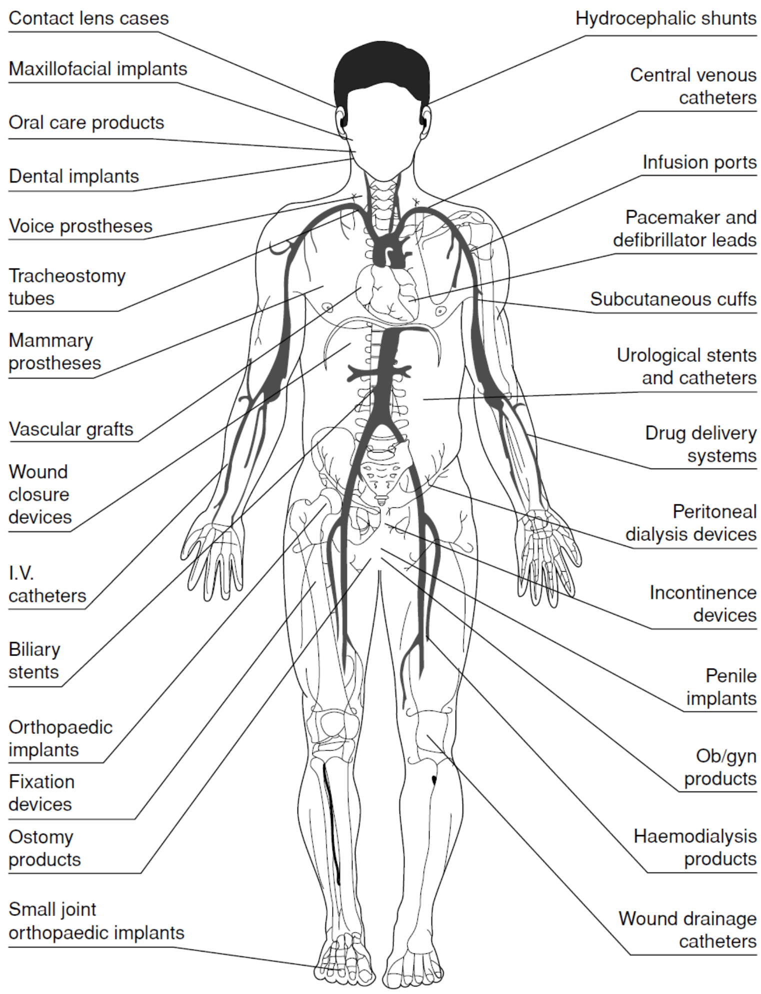

Figure 3.10 Examples of biomaterials used in medical products and devices[113]

DMA

DMA can be a useful technique for the characterization of biomaterials since material properties such as stiffness or damping can be determined. Application examples of DMA method used for biomaterials are as follows:

- Particulate and fibre reinforced polymer composites as bone substitute materials
- Absorption and hydrolysis behaviour of polymers and composites to assess its degradation characteristics
- Development of porous foams for tissue engineering

[113] Hill, 1998, Copyright John Wiley & Sons Limited. Reproduced with permission.

DSC

As a technique, DSC can be used for the characterisation of the thermal properties of polymers and composites used as biomaterials. The resultant graphs can be used to identify various numbers of parameters such as glass transition temperature (T_g), crystallisation temperature (T_c), melting temperature (T_m) and the heat of cure.

Examples of applications using DSC in the field of biomaterials are as follows:

- Locating of the polymer T_g and how this would change as a consequence of filler addition is being studied during development of degradable composite foams for bone tissue engineering.
- Polymeric material characterisation in dental and orthopaedic applications: Absorbable Polymers play an important role in the field of tissue engineering where scaffolds of Polymers can be combined with biological cells and then applied to bone regeneration.
- Thermal stability and degradation of collagen films and sponges

DTA

Bioceramics and bioactive glasses are biomaterials which are used in bone healing. Bioactive ceramics or glasses contain amorphous and crystalline regions which combine good mechanical properties of the material with additional bone-bonding abilities. Due to high transition temperatures, ceramics and glasses are typically assessed for their thermal properties using high-temperature DTA equipment.

3.3.5 Application to inorganic compound glasses and glass-ceramics

Thermal analysis gives a greater insight into inorganic compound glasses and hence can help to understand their nature. Glasses and glass systems that can be analysed with thermal analysis are intended to use for optical purposes as well as for various other applications.

DTA & DSC

Both differential thermal analysis (DTA) and differential scanning calorimetry (DSC) are techniques for determining temperatures of phase transitions like melting point, solidification onset and recrystallization onset. The difference of the sample temperature and the reference material temperature is measured with the DTA-method. It is an older technique than differential scanning calorimetry,[114] but DTA equipment has been used for the characterization of glasses and ceramics as it has the ability to measure at higher temperatures (~1500°C). In contrast, with the differential scanning method (DSC) the change of the difference in the heat flow rate to the sample and the reference material is measured. Unlike DTA, DSC allows a quantitative determination of heat capacity and also the enthalpy of a phase transformation. It is also more sensitive and rather more versatile than DTA.

TMA

Thermomechanical analysis (TMA) gives an accurate measurement of the change of a mechanical dimension of the sample under an applied temperature ramp. This allows measurements of a range of properties useful for characterising glasses, for instance linear thermal expansion coefficient, dilatometric softening point, viscosity–temperature behaviour of the glass-forming liquid, and so on. Thermal history of annealed glass can affect both the thermal expansion coefficient and the dilatometric softening temperature.
Annealing of glass is a process where it is slowly cooled to relieve internal stresses after the forming process.[115] Thus, TMA is an important method to determine the conditions for hot shaping, joining, annealing and avoidance of thermal shocking of inorganic glasses.

3.4 Alternative applications of thermal analysis

Although thermal analysis offers a range of techniques which have been applied for characterization of materials, the scope of this work has only allowed the most important and relevant ones to be covered (see previous chapter). Some more common applications of thermal analysis that have been identified are briefly mentioned below.

3.4.1 Thermal analysis in nuclear power generation

A further application of the thermal analysis technique is the characterization of materials in the field of nuclear power generation. Materials which are being used in nuclear facilities are carefully selected. The material-specific requirements such as thermal shock resistance and resistance to radiation and corrosion are of special importance.[116]

[114] Klančnik, Medved and Mrvar, 2009, pp. 128-129
[115] Tempered Vs. Annealed Glass. Definition from eHow, retrieved December 05, 2010, from http://www.ehow.com/about_5398576_tempered-vs-annealed-glass.html
[116] Joshi, 1978, pp. 1-8

Several thermal analysis methods such as DSC, TGA, DTA and TMA are used for the characterization of materials for nuclear applications. Some applications where thermal analysis methods have been applied for the study of material properties are as follows:[117]

- Optimization of the uranium transformation process where uranium from ore in the ground is extracted and converted and subsequently enriched for the use as fuel for nuclear power plants.[118]
- Monitoring and control of fuel fabrication process where uranium dioxide powder is pressed to fuel pellets and loaded into long tubes afterwards.[119]
- Investigation of material issues for nuclear-waste management. Nuclear waste which belongs to low-level waste (LLW) according to the U.S. classification system has to be stored in highly durable waste packages. Waste containers which are made of stainless steel provide protection against the nuclear waste.[120]
- Characterization of materials for reactor vessels. Nuclear reactor vessels are made of special metal alloys as they are exposed to high temperature and high corrosive atmospheres.[121]

3.4.2 **Characterization of paintings and coatings**[122]

Thermal analysis is a proven technology for characterization of paintings and coatings and helps to understand the relationship to process parameters (e.g., mixing time). Important techniques to study influencing factors and behaviour of coatings are stated below.

Dynamic-mechanical analysis (DMA) methods are being used to study film properties, the film-formation process and the material properties of paints after application. In this context, TGA is also a common used method for analysing the non-volatile content and thermal stability of coatings. For two-coat systems such as gel coats and laminating resin, the thermo-mechanical and dilatometric methods are suitable for determining the coefficient of thermal expansion (CTE).

[117] Setaram Brochure, 2008, pp. 2-11
[118] United States Nuclear Regulatory Commission, 2009, pp. 1-3
[119] Nuclear Energy Institute, retrieved December 05, 2010 from http://www.nei.org/howitworks/nuclearpowerplantfuel
[120] Yim and Murty, 2000, pp. 26-29
[121] United States Department of Energy, 1993, pp. 1-5
[122] Neag, 1995, pp. 841-864

3.4.3 **Characterization of printed circuit boards**

Thermal analysis can also provide information about the performance of materials used in printed circuit boards (PCBs).
Requirements to printed circuit boards used in electronic products range from increased thermal stability to proper mechanical properties. Hence, PCBs are constructed from woven fibreglass fabrics filled with epoxy resin. Both the style of used fiberglass and the degree of cured epoxy influence the nature of the PCB material.[123]

DMA is a suitable technique to determine the glass transition temperature of these epoxy/fiberglass mixtures. The degree of cure and the need of additional curing of the epoxy can be derived from DMA measurements.[124]
The DMA method allows studying the effect of delamination of printed circuit boards that may occur during production process. In a standardised test procedure for PCBs, the dimensional change of the material at elevated temperature is recorded. Information about the quality of the produced boards can be gained from the observation of the delamination time which is indicated by a steep increase of dimensional change.[125]

3.4.4 **Thermal analysis in electrical cable manufacture**

Cabling for power transmission and distribution has to maintain electrical integrity as well as it may be required to operate at relatively elevated temperatures and to continue providing service under fire conditions. As many of the materials used in cable manufacturing are polymeric, thermal analysis offers the possibility of investigating material behaviour at higher temperatures. In addition it is a useful method to verify the polymeric components and the ageing properties of materials.

In this field, DSC is applied for investigations of cross-linked polymeric products which are used in cable insulation.
Silicone rubber can be used as cable insulating material for applications where cables are designated to operate under fire conditions. Emergency lightning for example are exposed to maintain until evacuation is completed. The behaviour of such fire-retardant materials at high temperatures is studied with the thermo-mechanical analysis method.
Polymeric materials are very often used for cable sheaths and insulation. In TGA measurements, the combination of the weight-loss curve with the derivative has been found to be of value in studies of such materials.

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[123] Altera Corporation Application Note 528, 2008, pp. 5-8
[124] TA-Instruments Application Note TS-46, n.d., p. 1
[125] TA-Instruments Application Note TS-9A, n.d., p. 1

3.4.5 **Thermal characterization of asphalt**

Asphalt and asphalt-containing materials find application in construction of roads as well as in roofing of houses.[126]

One main criterion for choosing polymer additives in asphalt is to improve mechanical properties such as resistance to permanent deformation, fracture and high-temperature. That improved properties denote better durability performance of bituminous roof membranes[127] and increased thermal stability of asphalt mixtures for road surfaces.[128] TGA, DMA, DSC and different other thermal analysis methods have been used to investigate material properties of asphalt.

[126] Freemantle, 1999, p. 81
[127] Paroli and Delgado, 1996, pp. 38-40
[128] Mothé et al., 2008, pp. 105-106

4 Analysis of the Company – Case Study of Anton Paar

In order to identify the core competencies of the company, the two-step approach derived from Mind Tools has been used (see also chapter 2.1). First, important factors for customers in their decision making process of buying a product from Anton Paar have been identified. Afterwards, core competencies of the company have been identified that will provide competitive advantage by bundling the technologies, skills and capabilities within an organization into comprehensive competencies.

In continuation, it has been analysed whether and how several areas of the company including the product portfolio, the technological know-how, the sales and service network and the industries served by Anton Paar are related to the field of thermal analysis.

4.1 Important factors for customers

The goal of the first brainstorming phase was to find important factors for customers. The result is shown in Figure 4.1 and is also described in detail below:

- High quality: When customers are making investments for high-tech measuring instruments they are expecting to receive a high-quality product.
- Reliability: Anton Paar offers and distributes its goods and services mainly to other companies and thus the reliability of the equipment in terms of maintaining the required functions is very important. Furthermore it should also provide reproducible data under stated conditions.
- Service and Support: With the delivery of any device, the customer expects service availability 100% of the time.[129] Regardless if customers need technical support or if they want application support, it is always expected to have short response time to requests and to get comprehensive customer support from a highly experienced team.
- Technical guidance: There are many difficulties and challenges in business environment which companies have to overcome every day. In many cases business customers of Anton Paar are not able to describe the problem or to formulate what product or service exactly they really need. Hence, they require technical guidance to find proper solutions for their fields of application.

[129] Hiles, 2000, p. 2

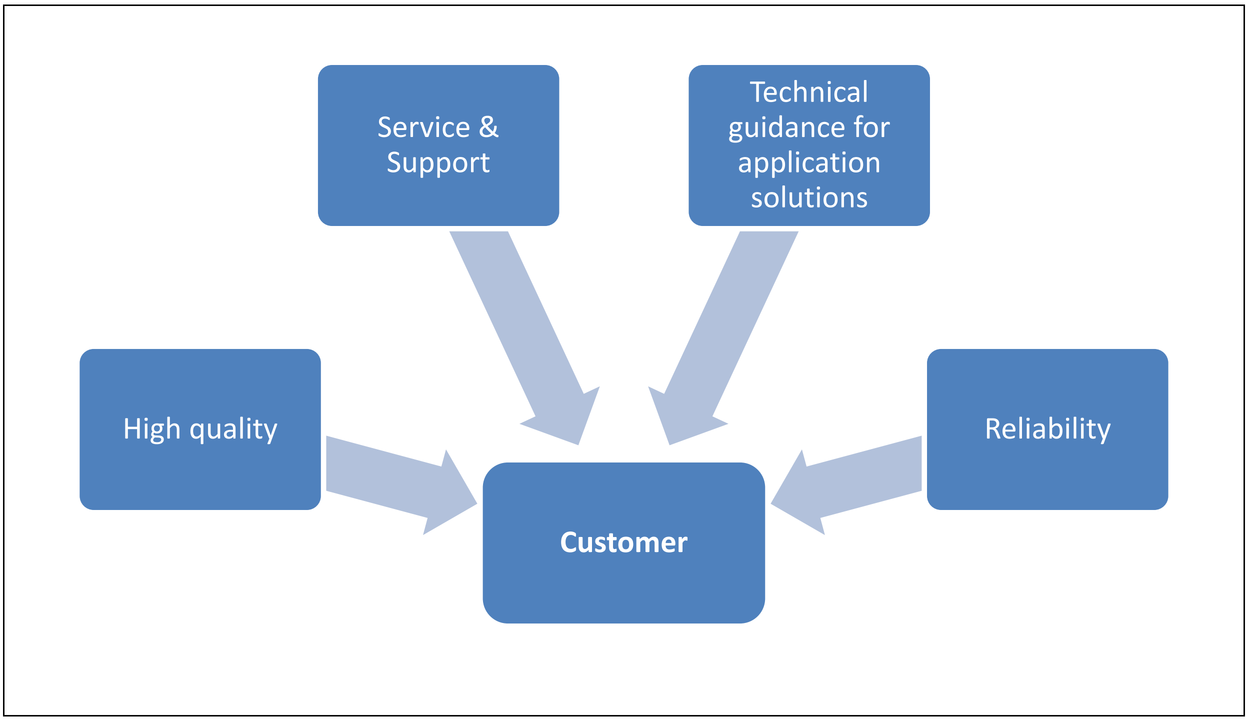

Figure 4.1 Important factors for customers of Anton Paar[130]

4.2 **Identification of core competencies**

In a second step, existing competencies of the company have been identified. Those competencies have been combined with the list of important factors for customers and were unified afterwards to the most important core competencies. Resulting from this process the core competencies of Anton Paar have been identified and are as follows (see also Figure 4.2):

- High-precision production: Anton Paar is known for the outstanding quality of its instruments which is based upon precise and modern production technologies.
- In-depth knowledge about liquids & fluids: Special knowledge in the flow behaviour of liquids and fluids as well as comprehensive skills in finding industrial applications has made the company a main contact partner for the food and beverage industry. This is also reflected in the company´s product range: Great number of products are measuring and determining physical parameters of liquids and fluids.

[130] Own illustration

- Product development competency: In order to be able to meet specific customer requirements, Anton Paar learned to combine information and issues from customers and to integrate them in the product development process.

- Expertise in analytical technologies: Over the last centuries the company has gained a lot of experience in developing, manufacturing and distributing measuring and analysis instruments. Furthermore, extensive knowledge for analytical technologies has been built up. This knowledge reflects the successful development of laboratory equipment and process instrumentation.

- Market shaping: Past experience has shown that the company maintained a close relationship with their customers. That enabled the company to understand identified gaps and develop innovative solutions to shape the market.

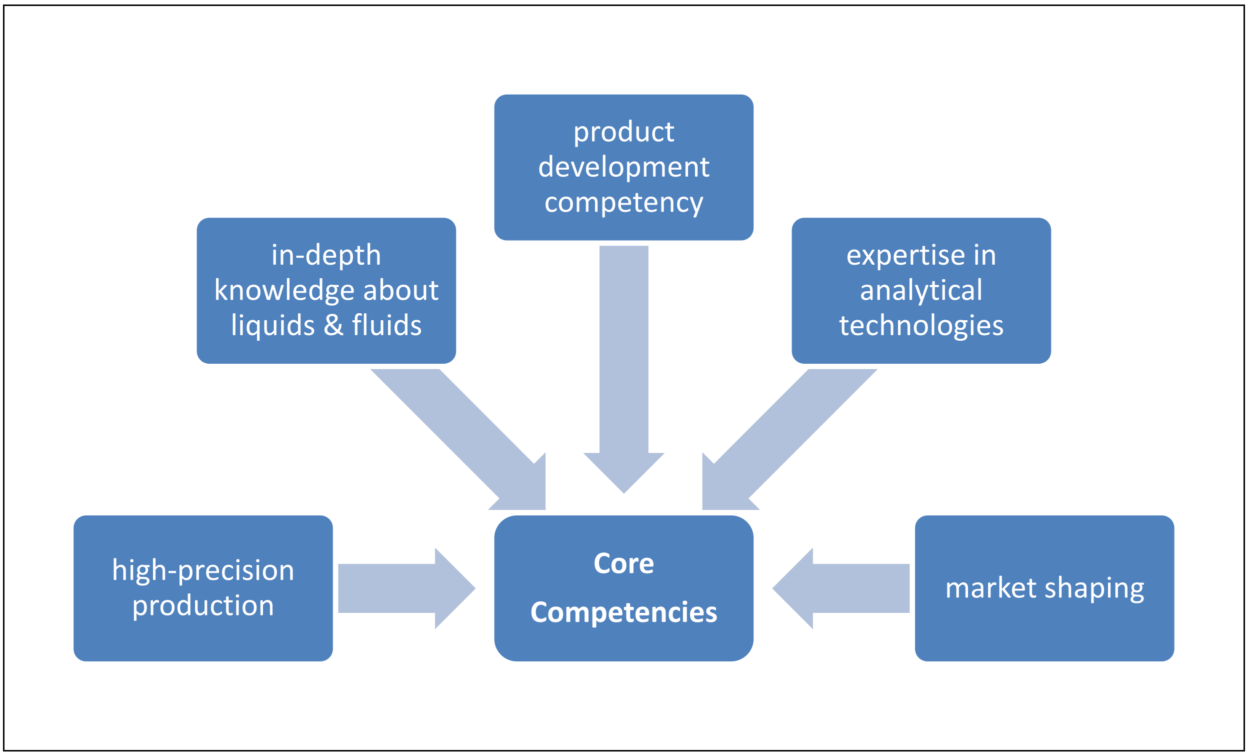

Figure 4.2 Core competencies of Anton Paar[131]

[131] Own illustration

4.3 Product portfolio of Anton Paar[132]

This chapter gives an overview of the complete portfolio of products that Anton Paar is currently manufacturing and distributing.

The company has six different product groups which are as follows:

1. Density and Concentration Measurement
2. Rheometry and Viscometry
3. Analytical and Synthetic Chemistry
4. Material Characterization
5. Refractometry and Polarimetry
6. Engineering & Production Services

4.3.1 Density and concentration measurement

The density is defined as the mass of a substance per unit volume. Density measurement is an important part of the analysis of material´s physical properties. Anton Paar produces and distributes density measuring devices based on the U-tube principle (see Figure 4.3). Hereby, a sample is introduced into a U-tube that is excited to oscillate afterwards. By determining the characteristic frequency of the sample, its density can also be obtained.

In addition to the density, the concentration of a mixture of two components can also be measured with proper devices. In this field, the company´s products can determine concentrations of carbon dioxide in beverages, sugar concentrations in soft drinks or alcohol concentration in alcoholic beverages.

[132] Anton Paar GmbH – presentation folder, 2009, pp. 1-22

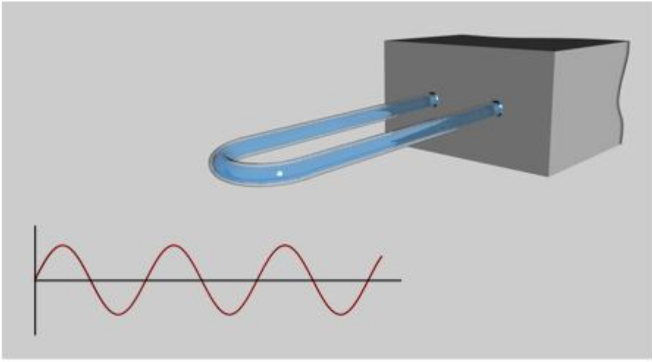

Figure 4.3 Oscillating U-tube principle for measurement of density[133]

4.3.2 **Rheometry and viscometry**

Rheology is the study of flow and deformation behaviour of different substances. With rheological experiments, information can be gained about the flow behaviour of liquids as well as about the deformation behaviour of "soft solids" and solids. To characterize the rheology of a liquid or solid, accurate measuring instruments called rheometers are used.[134] Figure 4.4 shows two rheometers from the product portfolio of Anton Paar.

Figure 4.4 Anton Paar rheometers, equipped with cylinder measuring system (left) and cone/plate measuring system (right)[135]

[133] Anton Paar image server, 2008, Oscillating U-tube principle
[134] Mezger, 2006, pp. 16-18
[135] Anton Paar image server, 2008, Physica MCR series 12

The viscosity is another important factor to describe the flow behaviour of liquids and gases. In all flowing substances, internal friction induces a resistance to flow. The measurement of flow resistance expressed by the viscosity of a fluid is done by viscometers. [136]

4.3.3 Analytical and synthetic chemistry

Sample Preparation

For the detection of traces of chemical elements in diverse products, an antecedent special preparation of the sample is often necessary. During a microwave-heated process with precise temperature and pressure control, the samples are finally converted to measuring solutions. These solutions can be used to analyse the composition of the base product.

Microwave Synthesis

Microwave synthesis is a common used technique in preparative chemistry. With this technique, a big reduction of reaction time from hours to minutes can be achieved. The principle is based on the combination of microwave heating and reactions under pressure which is applied on the sample.

4.3.4 Material characterization

X-ray Structure Analysis

X-ray structure analysis can be used to gain information and knowledge about the molecular structure of crystalline substances. From the diffraction of x-ray beams in a solid the arrangement of atoms within a crystal can be determined.

Electrokinetic Analysis

Colloidal systems consist of two substances where fine particles are dispersed in another substance called dispersion medium.[137] To describe the electrochemical interactions between the dispersion medium and a particle, colloidal measuring instruments can determine the zeta potential (electrokinetic potential) of colloidal systems.

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[136] Mezger, 2006, p. 19-28

[137] Colloid, 2010, Definition from Encyclopædia Britannica, retrieved December 06, 2010 from http://www.britannica.com/EBchecked/topic/125898/colloid

4.3.5 **Refractometry and polarimetry**

The refractive index of materials can be determined with refractometers. This index is used to assess the characteristics of materials and to ascertain the concentration of a substance (e.g., sugar) in liquids.

A polarimetric instrument measures the angle of rotation of a polarized light which passes an optically active substance.[138] The optical rotation method can provide information about the purity or the concentration of a solution. It is well-established method in the food & beverage and sugar industry.

4.3.6 **Engineering & Production services**

Anton Paar also produces high-precision mechanical components as well as fully functional complete devices including control unit. In production, modern machine tools provide a broad range of manufacturing technologies such as CNC, SMT or laser processing.

4.4 **Technological know-how related to thermal analysis**

This chapter will describe the existing technological know-how of the company in relation to the thermal analysis methodology. It also includes the overlap of in-house knowledge with fields from thermal analysis and shows to which technology the company has already access to.

Anton Paar develops and produces precise rheometers and also offers a wide range of system accessories and extension modules. During measurements, temperature variation has a great influence on rheological behaviour of materials. Hence, the company already developed various temperature control methods for its rheological measuring devices, ranging from temperature control with liquid circulators or Peltier elements to electrical or convective heating systems. Additionally, those heating systems can be combined with extension modules to clamp bars as well as films and fibres. Available fixture systems for different load types are shown in Table 4.1.

[138] Mayo, Pike and Forbes, 2010, p. 109

Typical applications of the dynamic mechanical analysis technology range from determining material properties of fibres, films, bars, rubbers and gels and other geometries. It is shown in Table 4.1 that system accessory for the rheometer already covers two kinds of loadings within DMA, to be specific torsion and tension. However, other loadings for sample geometries like single or dual cantilever bending, three-point bending, shear or even compression cannot be applied.

Table 4.1 Fixture systems available as accessories for the Anton Paar rheometer[139]

Type of loading	Sample type	Anton Paar nomenclature	Picture
Torsion	Rectangular bars	SRF: Solid Rectangular Fixture	
Torsion	Round bars	SCF: Solid Circular Fixture	
Tension	Films and fibres	SER: Sentmanat Extension Rheometer	
Tension	Films and fibres	UXF: Universal Fixture	

139 Own illustration, Data aggregated from Anton Paar image server, 2008

Overlap to fields of Thermal Analysis

The schematic representation in Figure 4.5 shows all different product groups from Anton Paar alongside the measuring principles of thermal analysis. The product groups on the left side from the schematic diagram are represented in accordance to the organisational structure of Anton Paar. A slight overlap of a certain area from the product group rheometry and viscometry with the dynamic mechanical analysis method from thermal analysis has been figured out. As described in chapter 4.3.2, the rheometer, which is one product within the product group rheometry and viscometry, already is able to conduct measurements according to the DMA principle. Of course, a rheometric instrument needs to be equipped with proper fixtures in order to clamp the sample. At the moment, fixtures are available for clamping solid round and rectangular bars as well as for films and fibres. Furthermore, Anton Paar´s rheometer only offers two loading types (tension and torsion).

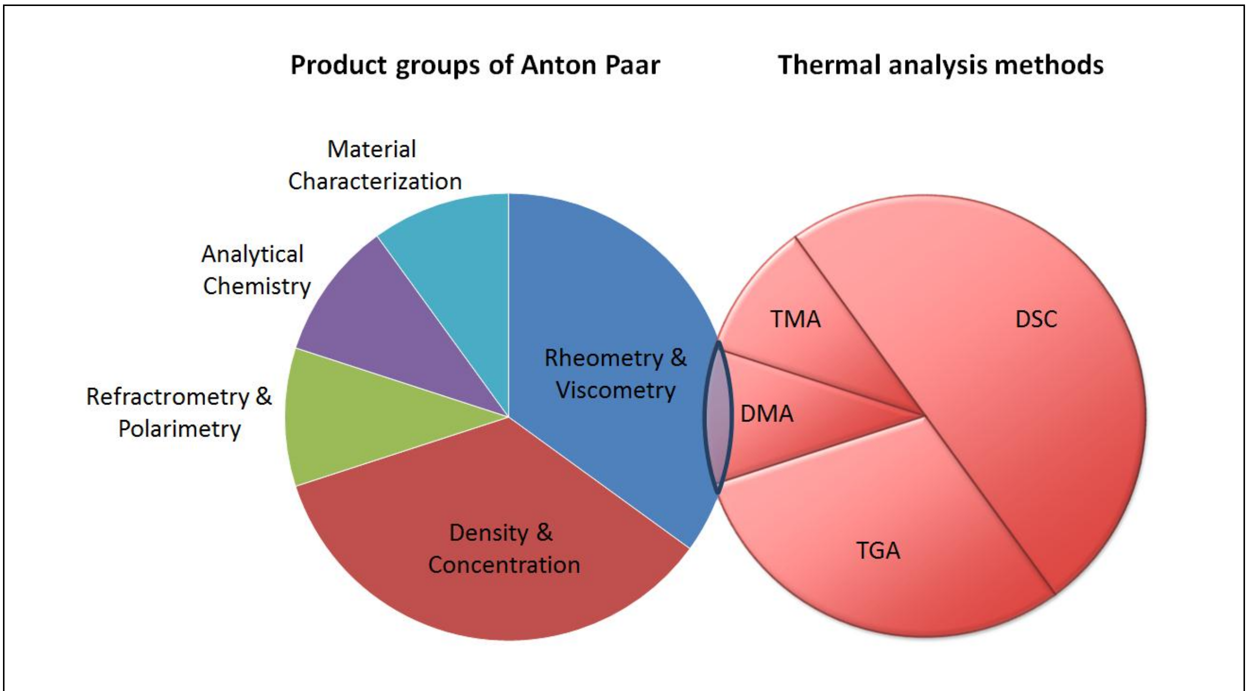

Figure 4.5 Small overlap of the DMA method with one product group from Anton Paar[140]

4.5 Sales and service network

The content of the respective section is the reflection of the company´s sales and service structure. For this purpose the current situation will be demonstrated and its suitability analysed for increasing product diversity.

[140] Own illustration

General statement

Anton Paar has a worldwide sales network to cover the requirements and needs of their customers. In addition, they offer a professional after-sales service which should guarantee rapid support in service cases.

Sales & Service structure

The strategy of the company is to offer a sales and service network aimed at providing comprehensive support for applications as well as for maintenance and service. The main sales and service activities are divided into two areas: Countries with regional subsidiaries and geographical regions with distribution partners. For each area equally the sales of new products should be complemented by local service and support. For countries with no subsidiary or distribution partner, the headquarters manages directly the business activities.

Figure 4.6 gives an overview of the global sales and service structure of Anton Paar.

Expansion plan

With the aim to introduce a new product, no major changes on the current sales strategy would be necessary since the competitiveness of international market oriented firms is greater than that of local oriented firms. However, a mature product launch process where both the sales force and the service team are well prepared and trained would lead to greater customer acceptance. Additionally, further preparations including a marketing plan, documentation and a production plan have to be made prior to the product launch.

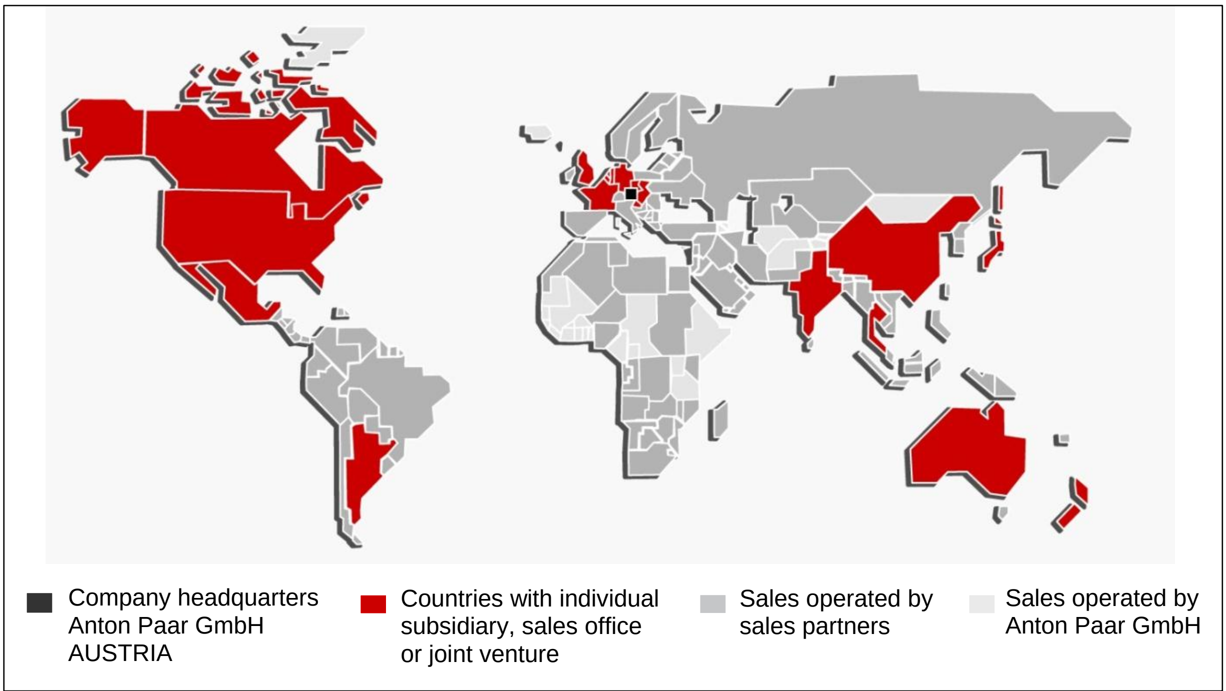

Figure 4.6 Worldwide Sales & Service network of Anton Paar[141]

[141] Anton Paar GmbH – company presentation, 2009, p. 9

4.6 **Industries served by Anton Paar**

As shown in chapter 3.3 and in chapter 3.4, thermal analysis is an established and widely used method in many areas. A summary which encompasses areas of application of thermal analysis methods is listed below:

1. Application to thermoplastics and rubbers
2. Thermal analysis of pharmaceuticals
3. Thermal methods in the study of foods and food ingredients
4. Application to biomaterials
5. Application to inorganic compound glasses and glass-ceramics
6. Thermal analysis in nuclear power generation
7. Characterization of paintings and coatings
8. Characterization of printed circuit board
9. Thermal analysis in electrical cable manufacture
10. Thermal characterization of asphalt

The two most important industrial applications in terms of sales volume are assessed to be the polymer industry and the pharmaceutical industry.[142]
A survey which was commissioned by Anton Paar showed that the thermal analysis market can be divided into five main business segments: [143]

1. Polymer Industry
2. Pharmaceutical Industry
3. Inorganic Chemistry (especially inorganic materials)
4. Food- and Food Ingredients Industry
5. Others

As a next step, these business segments have to be associated with the industry segments served by Anton Paar. Measuring instruments produced and marketed by the company are already used in numerous industries. Figure 4.7 gives an overview of current industry segments served by the company. Comparing Anton Paar´s industry segments with those

[142] G. Murer (personal communication, October 09, 2010), Business Development Manager
[143] Company internal information - market overview of thermal analysis, 2009, p. 3

from thermal analysis, there won´t appear any new industries which are of relevance for thermal analysis methods and are completely unknown for Anton Paar. In other words, the company already has access to all the industries which are of importance in the area of thermal analysis. This shows that entering into the new thermal analysis market would not be a completely new field for Anton Paar. Hence, existing knowledge about customer requirements could have a positive effect on the development of a new business field, namely thermal analysis.

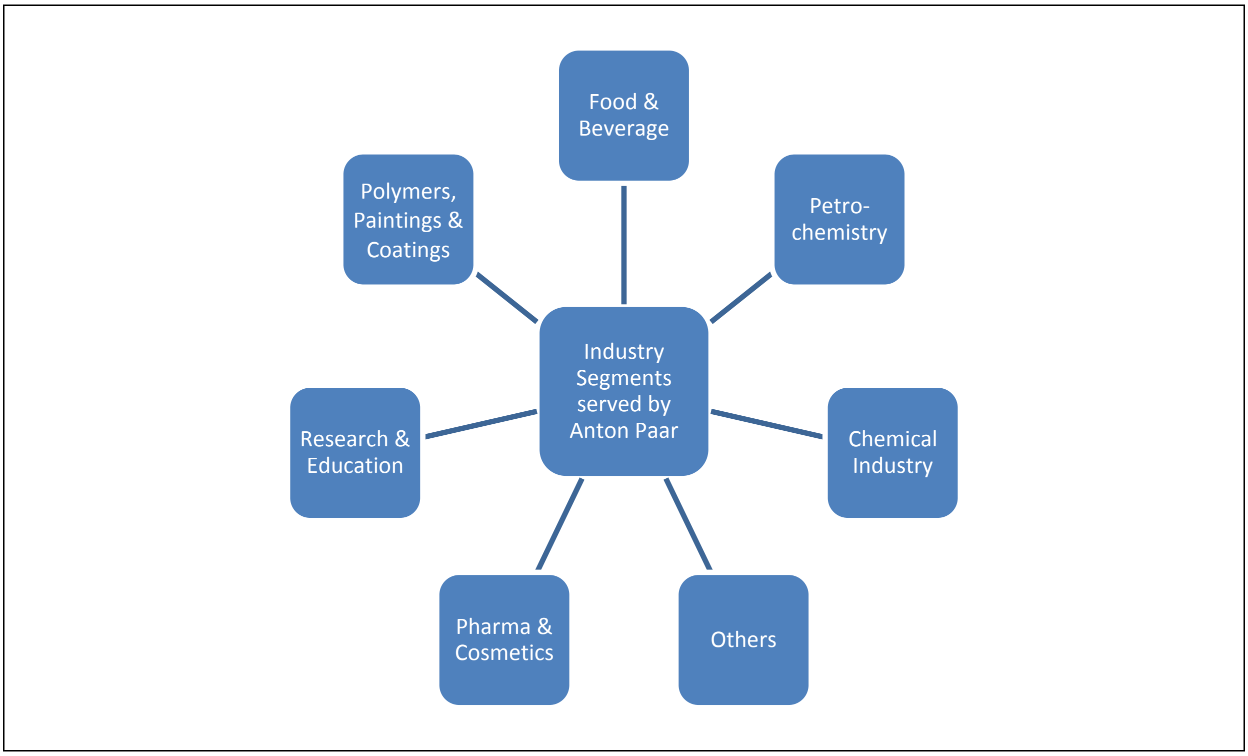

Figure 4.7 Industry segments served by Anton Paar[144]

[144] Own Illustration, Data aggregated from Anton Paar GmbH website, retrieved December 06, 2010, from http://www.anton-paar.com/Industries/3_Corporate_en

5 Analysing the Market

5.1 Overall market size for thermal analysis equipment

Collected information from in-house data sources showed that the global market for thermal analysis instruments can be assumed with US $330 million by 2008. Furthermore, a decrease in sales of 10% to 15% for the fiscal year 2009 was presumed. Because of the on-going worldwide economic crisis this reported decrease in sales was assessed to reach US $290 to US $300 million in 2009.[145]

Another approach to understand the industry and to estimate the market size is to use annual reports of companies which are conducting their business in this area.[146] The US company TA Instruments is chosen in this case. Along with Waters Division, the TA Division is an operating segment of the publicly traded company Waters Corporation. The TA Division manufactures and distributes thermal analysis, rheometry and calorimetry instruments. The company also develops and supplies software solutions for the company´s instruments as well as for other manufacturers´ instruments.[147]

In the company´s annual report, the net sales for products and services of TA Instrument systems was total US $147,6 million, of which US $109,3 million was accounted for TA Instruments’ products and US $38,24 million was reported for TA services. Based on internal information from Anton Paar[148], the TA Instruments´ thermal analysis sector accounts for about 80% of total sales and the remaining 20% being split between rheometry and calorimetry instruments.

Anton Paar estimates that TA Instruments possesses market share of approximately 35% which is the largest share in the thermal analysis market.[149] Considering the given figures, the global market for thermal analysis products and services can be estimated with US $337,4 million for 2009.

The validity of this study was confirmed by comparing the company´s market research data with the estimation of the global thermal analysis market as demonstrated above. Summarizing these study´s findings, the market size of the global thermal analysis products and services is expected to have reached US $330 million by 2009. As already shown in the case of TA Instruments, revenue from new products can be expected to be between 70% and 80%, consequently services account for 20% to 30%.

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[145] Company internal information - market overview of thermal analysis, 2009, p. 1
[146] Porter, 1980, p. 371
[147] Waters Annual report, 2009, p. 3
[148] G. Murer (personal communication, October 09, 2010), Business Development Manager
[149] Company internal information - market overview of thermal analysis, 2009, p. 1

5.2 Market segmentation by industry

In this chapter, the thermal analysis market will be segmented with reference to the demographic segmentation method of business markets shown in chapter 2.2.2. The market was segmented into the four industries polymer industry, pharmaceutical industry, inorganic material characterization and food and food ingredients industry. Further branches with a market share lower than 5% are mentioned in the category "Others". The distribution of market shares is based on company internal data.[150]

The largest of these four segments is the polymer industry, which accounted for about half of the overall market in 2008. Next largest by size is pharmaceutical industry at approximately 20% of the overall thermal industry market. As seen in Figure 5.1, these two industries represented approximately 70% and formed the largest group of end use segments for thermal analysis equipment.

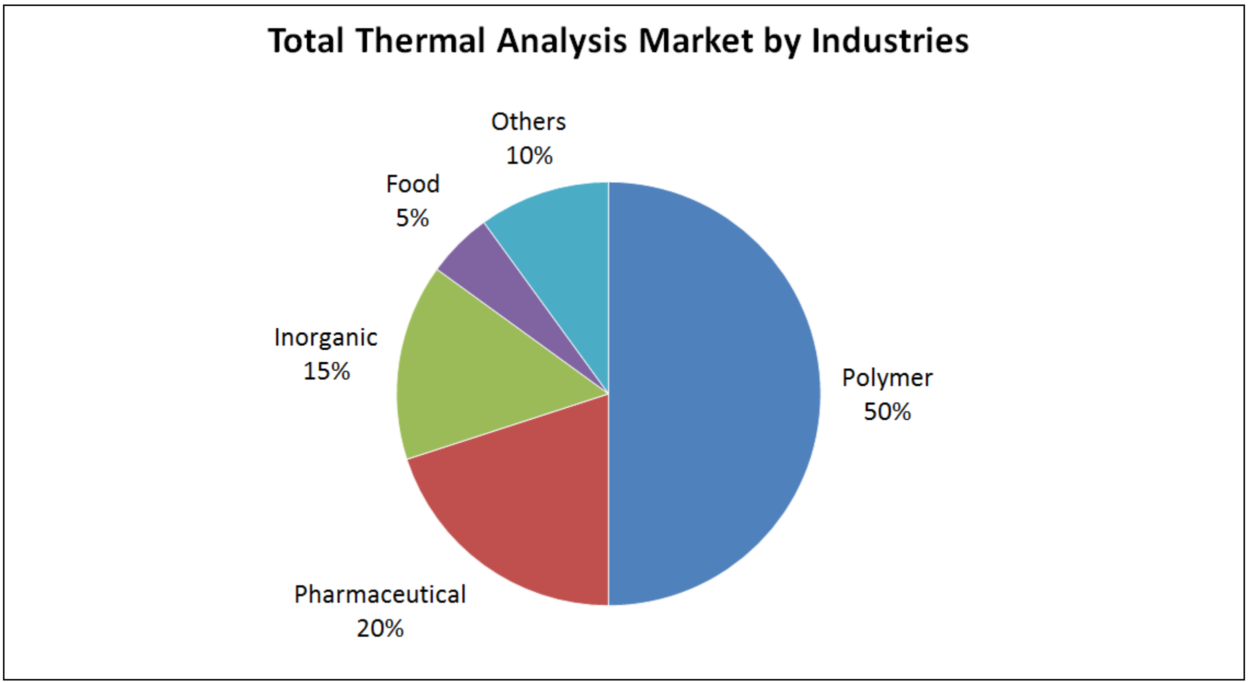

Figure 5.1 Thermal analysis market share distribution in %, Year 2008[151]

[150] Company internal information - market overview of thermal analysis, 2009, p. 3-4

[151] Own Illustration, Data aggregated from company internal information - market overview of thermal analysis, 2009, p. 3

5.3 Future directions

This chapter covers future projections and directions of the thermal analysis market. Although no accurate figures could be figured out, a few important market trends have been identified.

Global market development

A global study published by Global Industry Analysts about the market of calorimeters and thermal analysis equipment provided information about different market trends. In this study, the global market was analysed and subsequently segmented by calorimeters and thermal analysis equipment. In the global market analysis for thermal analytical equipment, the largest product group was estimated to reach US $429 million by 2012.[152]

Growth potential

The Asia-Pacific region may be considered as a potential growth field for thermal analysis equipment. Market growth in the Asia-Pacific region for thermal analysis and calorimetry equipment was expected to reach a compound annual growth rate of 4,8% over the years 2011 through 2015.[153]

In a report published by the Indian Analytical Instruments Association, India as an emerging country among Asia-Pacific nations has been identified to have a future growth potential for the thermal analysis market.[154]

In contrast, important markets for calorimeter and thermal analytical equipment have been in the past the United States and Europe with a combined market share estimated at 71% in 2008.[155]

Laboratory Equipment World underlined in their study about laboratory analytical instruments the significance of the pharmaceutical industry for the worldwide market.[156] It was estimated that approximately 40% of total revenues was contributed to the pharmaceutical industry. Furthermore, considering the laboratory analytical instruments market, a movement in a westward direction towards the United States was also mentioned because they provide a framework through which research and development activities are promoted.

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[152] Vocus Inc, 2008, p. 2

[153] Vocus Inc, 2008, p. 2

[154] Gopalakrishnan - Indian Analytical Instruments Association, n.d., pp. 1-2

[155] Vocus Inc, 2008, p. 1

[156] Laboratory Equipment World, retrieved December 05, 2010, from http://www.laboratoryequipmentworld.com/laboratory-analytical-instrument-industry.html

Importance of pharmaceutical science

The largest demand for thermal analysis instruments comes from the polymer industry as seen in chapter 5.2. But the pharmaceutical sector will also become of increasing importance in the future. READING/CRAIG for example described how various thermal analysis principles can be used to study problems in the pharmaceutical area. Differential scanning calorimetry (DSC) can be stated as the most widely spread method within the pharmaceutical field.[157]

However, the dynamic mechanical analysis principle (DMA) is also gaining increasing significance in pharmaceutical and related industries. This is partly due to the fact that polymers and polymer biomaterials are of special interest in pharmaceutical applications and the DMA measuring principle can provide valuable information about viscoelastic properties of polymers.[158]

To conclude the importance of the pharmaceutical industry for thermal analysis, a statement from Waters Corporation can be mentioned where the strategic orientation of TA Instruments towards the field of pharmaceutical and life sciences was explained.[159] TA Instruments currently has the largest market share in the thermal analysis equipment market.[160]

5.4 Technology portfolio analysis for target market selection

The suitability of the technology to the company´s resources and capabilities will be evaluated in this section. At the moment, Anton Paar is not capable to serve the entire thermal analysis market with analytical instruments. Hence a further selection of one suitable technology allows a targeted market analysis which is necessary for a successful market entry. The four thermal analysis methods DSC, TGA, TMA and DMA have been considered in chapter 3.2, of which one method will be selected now. The methodical approach of the technology portfolio analysis described in chapter 2.3 is used to find out one thermal analysis method which will be best suited for a sustainable development of Anton Paar´s business.

All data used for the assessment of proposed options for the targeted market are based upon information provided by and agreed with the corporate development department of

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[157] Reading and Craig, 2007, p. 1
[158] Jones, 2007, p. 324
[159] Bouley, 2007, p. 1
[160] Company internal information - market overview of thermal analysis, 2009, p. 3

Anton Paar.[161] For the rating of different criteria, a scaling ranging from 0 to 5 points has been used. The basis of scoring, which was used for all criteria, is shown in Table 5.1.

Table 5.1 Allocation of points for assessment criteria[162]

Compliance	Rating
very good, high	5 points
medium, equal, average	3 points
small, low	0 points

The criteria know-how level, potentials and time needs herewith describe the resource strength of the company. In the assessment of different options shown in Table 5.2 the two criteria know-how level and time needs have been considered as more important. Thus, those criteria have been weighted by factor of 2.

The ratings for the individual criteria are as follows:

Table 5.2 Weighting and rating of resource strength criteria[163]

Technology	Know-how level	Potentials	Time needs	Total
Weighting	2	1	2	
DSC	3	0	0	6 points
TGA	0	0	0	0 points
TMA	3	0	0	6 points
DMA	5	5	5	25 points

As seen in Table 6.1, the highest resource strength was assigned to the DMA method. This is mainly attributable to existing knowledge about DMA in conjunction with Anton Paar´s product segment of rheometric devices. However, basic knowledge about DSC and TMA methods has been gained from the field of X-ray diffraction where those combined methods are also used for material characterization. It was assessed that significant financial resources and a certain amount of time would be needed to reduce the gap to the

[161] G. Murer (personal communication, October 12, 2010), Business Development Manager
[162] Own illustration, Adapted from Baum, Coenenberg and Günther, 2004, pp. 222-223
[163] Own illustration, Adapted from Baum, Coenenberg and Günther, 2004, pp. 222-223

competitors in terms of technological competence. Hence all other methods except DMA have been rated low for the criterion potentials as well as for the criterion time needs.

For the assessment of technology attractiveness, the criteria development potential, application volume and compatibility have been used. As shown in Table 5.3, development potential and compatibility have been weighted by factor of 2, hence seen as more important. The ratings for individual criteria regarding technology attractiveness are as follows:

Table 5.3 Weighting and rating of technology attractiveness criteria[164]

Technology	Development potential	Application volume	Compatibility	Total
Weighting	2	1	2	
DSC	0	5	3	11 points
TGA	0	3	3	9 points
TMA	0	3	3	9 points
DMA	3	3	5	19 points

Table 5.4 provides an overview of different technologies with the corresponding rating, broken down by the two dimensions technology attractiveness and resource strength. Considering the weighting factors and the points given for each criterion, the maximum value of 25 points was achievable. These maximum points have been converted to the scale of 100%. Based on the percentage distribution, the different technologies have been positioned in the technology portfolio.

Table 5.4 Overview of thermal analysis technologies with corresponding points expressed in %[165]

Technology	Resource strength	Technology attractiveness
DSC	24%	44%
TGA	0%	36%
TMA	24%	36%
DMA	100%	76%

164 Own illustration, Adapted from Baum, Coenenberg and Günther, 2004, pp. 222-223
165 Own illustration, Adapted from Baum, Coenenberg and Günther, 2004, pp. 222-223

Figure 5.2 shows the technology portfolio with positioned thermal analysis technologies. Since no information has been available about the strategic importance of each technology, they have been represented in dots of equal size.

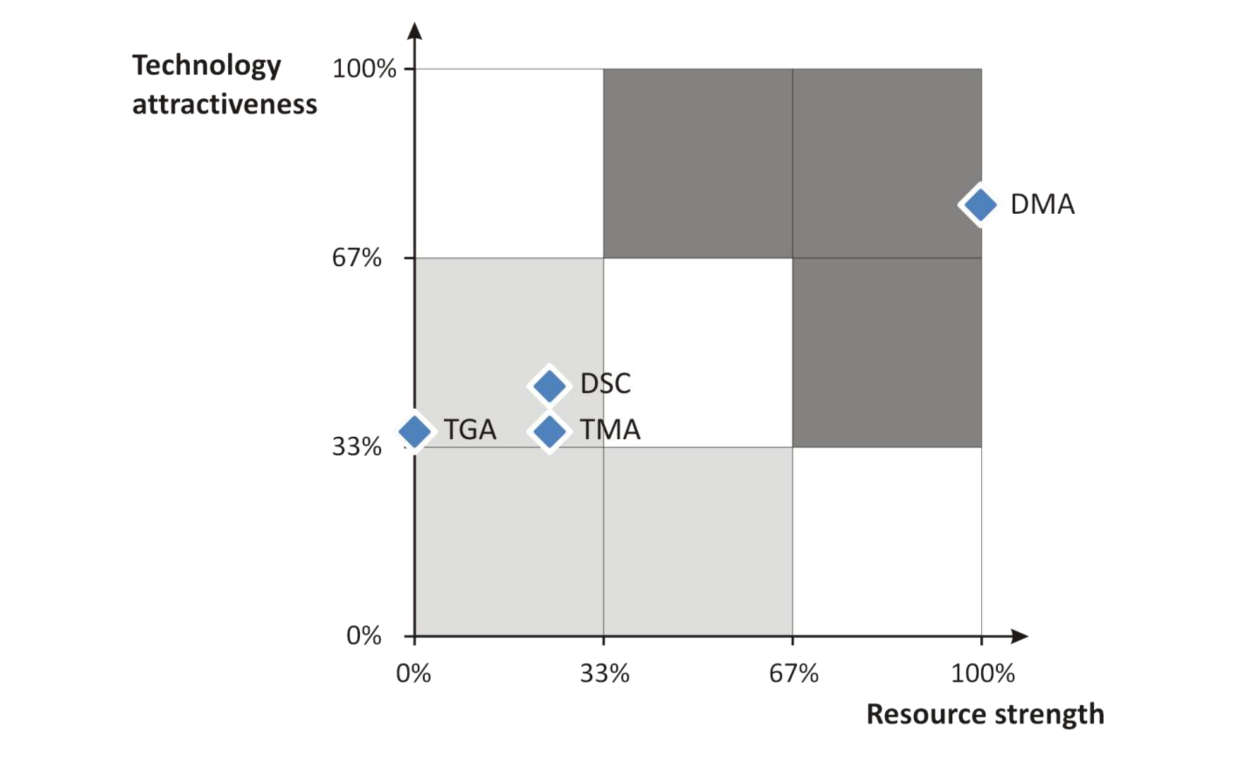

Figure 5.2 Technology portfolio including positioned thermal analysis technologies from the perspective of Anton Paar[166]

Now the results can be compiled in order to analyse different technologies and determine its suitability for Anton Paar. On the basis of the technology portfolio analysis, no further investments are recommendable in the field of DSC, TGA and TMA. As such technologies do not yet exist in the product portfolio of Anton Paar, the company would enter completely new territory. On the other hand, DMA as a technology positioned in the area of the standard strategy for investment recommendations is subject for further considerations now. In accordance with the standard strategies described in chapter 2.3.2, the high resource strength in field of dynamic mechanical analysis principles should be promoted and extended. The high resource strength in this field is attributable to Anton Paar´s high technological competence and know-how gained in the development of rheometric devices. Those rheometers are instruments not only suitable to study the flow behaviour of different substances, but also DMA measurements can be made with suitable accessories.

[166] Own illustration, Adapted from Baum, Coenenberg and Günther, 2004, p. 223

To conclude the target market selection process, the DMA principle emerged to be recommendable to make further investments. Consequently, later considerations about the market and according product development strategies will be mainly focused on the dynamic mechanical analysis (DMA) principle.

5.5 Competitive analysis

This chapter provides an overview of the major players as well as smaller companies in the field of thermal analysis. Special focus was given to the DMA principle, which was considered and described in previous chapter as being the targeted market segment. There are many different companies selling various types of dynamic mechanical analysis which have been identified. However, the goal of this chapter was to give an overview of the main players with special emphasis on DMA. Data were collected from information available on public domain.

The study was based on and carried out by following criteria:

- Identification of companies active in the field of thermal analysis
- The company of interest must be a manufacturer of thermal analysis equipment; distributors which only offer and sell thermal analysis products have been excluded
- The company must have at least one product with the DMA measuring principle in their product portfolio

Identification of companies

In this section investigations were made about the major companies in the thermal analysis industry in order to gather a better understanding of the industry´s characteristics. The first step was the identification of companies in the industry. In continuation, fact-sheets have been worked out for each of the companies which were identified as major players.

Table 5.5 lists some of the commercial DMA instruments which are currently available on the market. As noted, fact-sheets with detailed company information are available for the companies listed under (a) major players. Companies which are mentioned under (b) other vendors are usually smaller companies with a limited product portfolio. Those smaller companies are only listed in Table 5.5 and no fact-sheets are available.

Table 5.5 Different DMA instruments from some current manufacturers[167]

Manufacturer	Model	Contact Information
(a) DMA Instruments from Major Players		
TA Instruments Inc (US)	Q800	www.tainstruments.com
	RSA III	
Mettler-Toledo International Inc (Switzerland)	DMA/SDTA 861e	www.mt.com
Perkin Elmer Inc (US)	DMA 8000	www.perkinelmer.com
Netzsch Group (Germany)	DMA 242 C	www.netzsch.com
SII NanoTechnology Inc. (Japan)	EXSTAR DMS6100	www.sii.co.jp
(b) DMA Instruments from Other Vendors		
01db-Metravib (France)	DMA 25	www.01db-metravib.com
Triton Technology Ltd (UK)	TT DMA	www.triton-technology.co.uk
GABO QUALIMETER Testanlagen GmbH (Germany)	EPLEXOR® series	www.gabo.com
Bose Corporation, ElectroForce Systems Group (US)	ElectroForce® 3100	www.bose-electroforce.com
Linseis Messgeraete GmbH (Germany)	TMA - PT1000	www.linseis.net

The fact-sheets which have been worked out for each of the companies classified as major player are shown in Appendix A. Those fact-sheets include information about each company regarding their published corporate financial data and the products from every business units. Relevant facts and figures to the number of employees and the worldwide locations are listed in the section of global footprint.

As a second step, the product portfolio of thermal analysis instruments has been examined in greater detail. Therefore all thermal analysis instruments including the number of different available device types have been identified and documented subsequently. Finally, special focus was given to the DMA instruments of each company.

[167] Own illustration

Technical specification of the DMA instruments included the range of temperature, frequency, force, displacement, damping factor, stiffness and modulus.

5.6 Structural analysis of the thermal analysis industry with special focus on one market segment

In the case of Anton Paar, the company is going to decide whether it will enter the thermal analysis market by extending its technological competence in the field of DMA. Figure 5.3 shows the five forces framework which is adapted now to help analysing the situation of Anton Paar and the existing thermal analysis market. For this purpose it was assumed a model where the company is considered to be in the position of a DMA technology provider in a context of active competition.

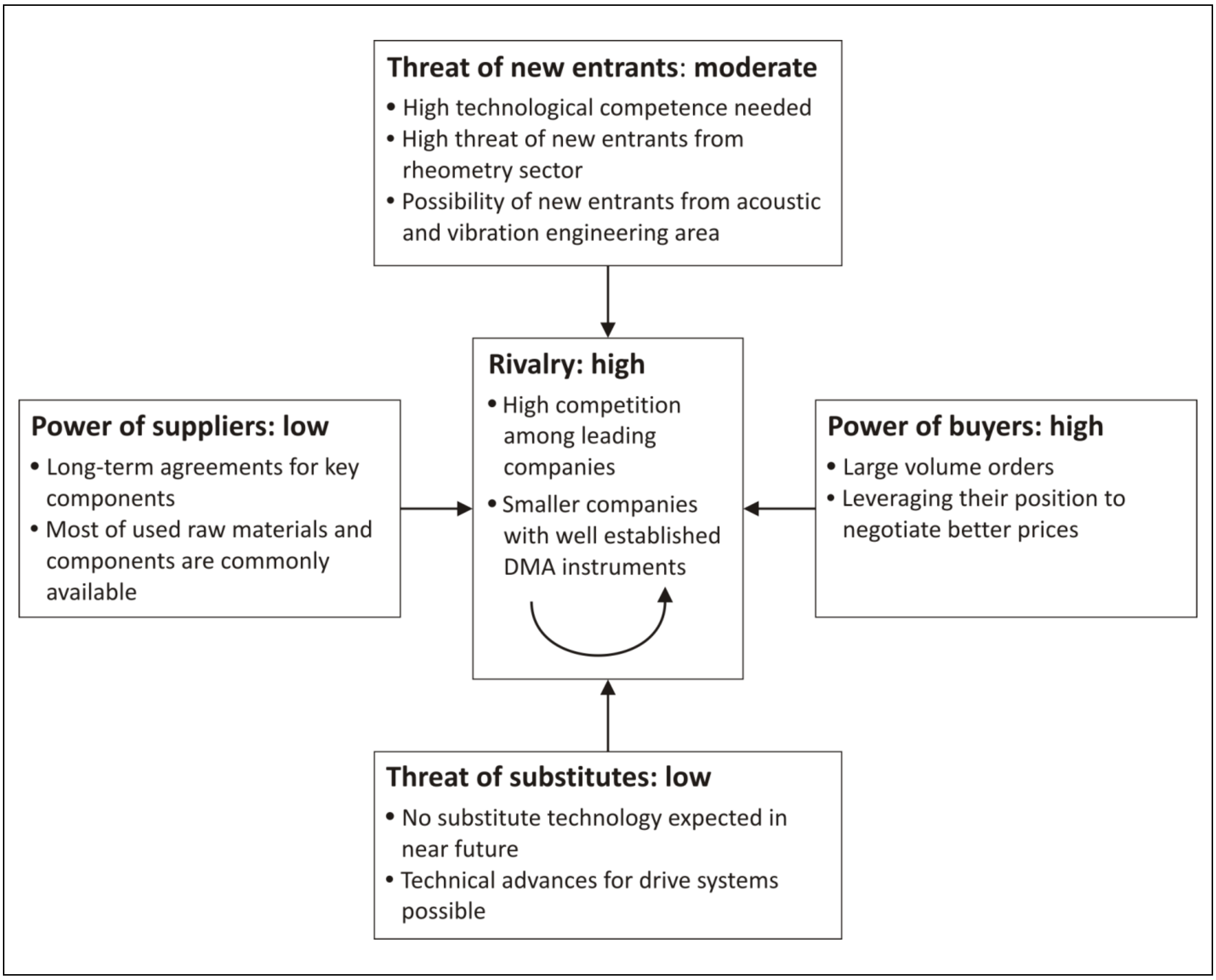

Figure 5.3 Porter´s five forces framework of competition adapted to the thermal analysis industry with special focus on the DMA market segment[168]

[168] Own illustration. Adapted from Porter, 1985, p. 5

Threat of new entrants

The threat of new entrants is assessed to be moderate. High technological competence is needed for the development of a suitable DMA instrument and hence the barrier to entry is high. The experience and technological know-how is also considered to be a precondition to achieve successful product innovations and near-to-market development results. On the other hand, know-how about technologies that are closely related to the field of dynamic mechanical analysis may lower the barriers to entry. Further explanations regarding areas related to the DMA method are considered below.

In order to give an estimation for the threat of new entrants in the future, aspects which include adjacent areas to the DMA technology are examined in greater depth. As the DMA method investigates the characteristic of materials by applying an oscillating force at a certain frequency, similar areas are considered where dynamic mechanical oscillation techniques are also used. This includes areas like rheological investigation and other disciplines for analysing vibrations in engineering systems.

Anton Paar is already competing worldwide with manufactures of rheological measuring devices. In this context, the probability that rheometer manufacturers also will enter the thermal analysis market is quite high. Companies like Malvern Instruments Ltd or Brookfield Engineering Laboratories Inc which have gained knowledge in applications of dynamic mechanical measuring technologies are likely to expand their business to the field of thermal analysis. Two other big companies which produce and distribute analytical measuring devices and in particular rheometers could also be mentioned here. Both Thermo Fisher Scientific Inc and also Waters Corporation already launched successfully thermo-analytical instruments on the market. This confirms the former assumption of possible entrants coming from the field of rheometric instrumentation.

CROCKER described that “The vibrations in machines and structures result in oscillatory motion that propagates in air and/or water…” and explained in his book the link of vibrations to acoustics and sound.[169] The study of noise and vibration control is closely related to the principles of dynamic mechanical analysis methods where mechanical oscillations are externally excited. Hence, manufacturers of acoustic and vibration control systems primarily benefit from their existing knowledge and may transform this to other areas like those of DMA. The company Metravib is held up as an example of taking the entry strategy into the DMA market proceeding from the acoustic and vibration engineering area.

[169] Crocker, 2007, p. 1

Power of suppliers

The bargaining power of suppliers is considered to be low. For certain key components or critical raw materials, long-term purchase agreements with suppliers may be concluded. In addition, several measures may be adopted in order to maintain a strong relationship with one supplier or to pursue a parallel sourcing strategy. However, most of the raw materials and components used for the manufacturing of such devices are commonly available in industry and can be sourced from different suppliers.

Power of buyers

The buyer power is likely to be high if there is a concentration of buyers or even large companies such as multinational corporations order products and services in high volumes. Past experience from Anton Paar has shown that powerful buyers have benefited from large order volumes in terms of price and conditions.[170] Therefore customers which leverage their position to achieve better price agreements can be expected.

Threat of substitutes

Taking account of the current situation on the market of dynamic mechanical analysis instruments, it is expected that no substitute products or technologies can be found in the near future. Analysis methods which are based on physical-chemical processes to investigate the molecular structure of materials might also be suitable for material characterization. However, the probability is estimated to be low that the DMA principle will compete in future against technologies for material characterization such as the X-ray scattering method. The success of devices for molecular structure analysis on the DMA market would be limited as they have a greater complexity and hence a higher price.

The drive systems are a key topic for DMA measuring instrumentations as they are of great importance for an optimal positioning of the clamping systems, including the samples.[171] Current drive systems are based on different technologies like those including magnetic coupling, air bearings and servo-mechanical actuators or combinations of these. However, new technologies suitable to realize alternative and better drive system concepts may arise in future. For example, further developments in piezoelectric technology could be applied to deliver a substantial increase in accuracy in measuring dynamic mechanical properties.

Although technologies like X-ray scattering can deliver similar information like DMA and alternative technologies for drive systems will establish, the future development of this aspects is uncertain and hence the threat of substitutes is assessed to be low.

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[170] G. Murer (personal communication, November 4, 2010), Business Development Manager

[171] Chartoff, Menczel and Dillman, 2009, p. 478

Competitive rivalry

The thermal analysis market is assessed to be highly competitive. According to PORTER, the intensity of rivalry depends on the structure of competition.[172] A highly competitive market may result where the competitors are equal of size. In contrast, the rivalry is less intense when there is a clear market leader. To analyse the competitive structure within the thermal analysis market, the competitors are shown in Figure 5.4 and are listed in descending order with respect to their market share. As no reliable and current data was available for the DMA market, considerations have been made about the overall thermal analysis market.
As seen in Figure 5.4, the largest player in the thermal analysis market was TA Instruments, which accounted for just over a third of product sales of the $331 million market in 2008. Next largest by size was Mettler-Toledo at 17% of the total thermal analysis market. Figure 5.4 shows that in 2008 around 83% of the global market were dominated by five companies.

This can also be related to the concentration ratio which reflects the percentage of industry sales that is accounted for by x number of companies in that industry. As described by ARNOLD, the x number can be any number of companies, although four and eight is normally used and the number is small too. A high concentration ratio implies that few companies account for a larger portion of industry output. In this study, the concentration ratio of five companies was determined because further considerations also have been referred to the five major players.[173]

With regard to the DMA market, the rivalry is also assessed to be high among existing competitors, although the competition is not as fierce as like in other thermal analysis market areas (such as DSC). Chapter 5.5 showed that DMA products are already available on the market from the five leading companies, namely TA Instruments, Mettler-Toledo, Perkin Elmer, Netzsch and SII/Seiko. In addition to that, other smaller companies like Metravib or Triton also have well established their DMA products on the international market. It can be expected that the companies continue to improve the design and performance of their products and compete on the market with new products to competitive prices.

In order to summarise these considerations, the different aspects are mentioned briefly again. The largest proportion of the total thermal analysis market is related to five companies. But also smaller companies offer a wide range of products and seek to expand their market presence. Hence, the rivalry among the companies is assessed to be high.

[172] Porter, 2008, pp. 6-7
[173] Arnold, 2008, p. 513

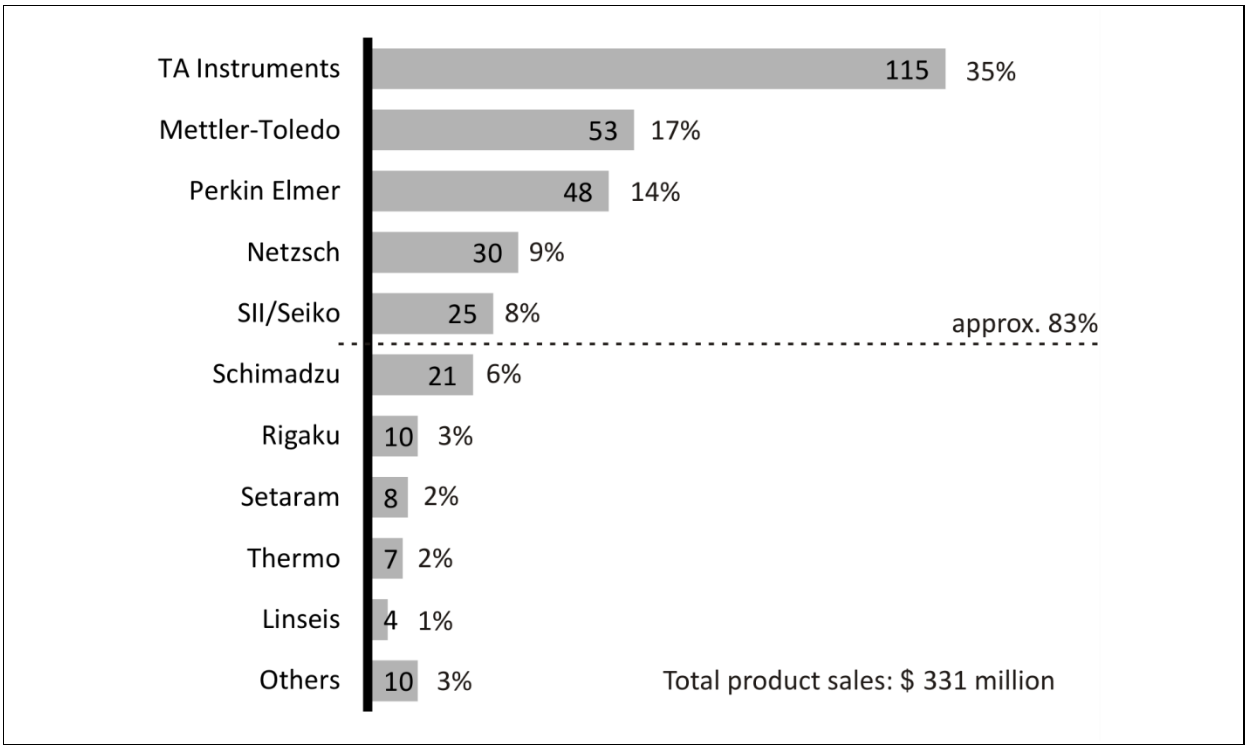

Figure 5.4 Worldwide thermal analysis market situation in 2008 - product sales in million Dollar and companies´ market share as % of total market[174]

[174] Own illustration, Data aggregated from company internal information - market overview of thermal analysis, 2009, pp. 3-4

6 Product Development Strategies for the Thermal Analysis Market

6.1 Identification of customer requirements

The process of identifying customer needs is an integral part of the product development process as described by ULRICH/EPPINGER. The aim of the identification of customer needs is to create valuable information that comprises a good basis on which developers can design products or solutions and experience from expressed needs. By evolving this direct experience, it is easier to exploit the potentials of a technology and find innovative solutions for specific problems of customers. Hereby, the analysis and identification of the needs is linked to the concept development phase (see Figure 2.5) and includes a competitive benchmarking as well as the establishment of product specification.[175]

ULRICH/EPPINGER explained methods how valuable information from the customers can be gathered and hence customer needs may be recognized. One effective method is to conduct interviews either with one customer separately or with a group of key-users. Another way to create high-valuable information is to observe the product when it is in use. The latter method has been used by Anton Paar to reveal important facts about customer needs. Within this work the focus was set on the product observing method to obtain raw data from customers.

Figure 6.1 shows the results of interpreting the customer needs underlying the raw data gathered from the customers. The process of identifying customer needs included a series of measurements which have been conducted with competitors´ instruments.

[175] Ulrich and Eppinger, 2004, pp. 53-70

The DMA instrument determines complex mechanical properties of materials.

It can be used to study molecular structures of materials including polymers, food, metals, biomaterials and other viscoelastic materials.

It detects phase transitions of the sample.

It determines mechanical properties – complex modulus and damping factor of different materials.

The DMA instrument provides high convenience.

It is easy to use.

It allows easy handling of samples, tools and clamping systems.

It provides an intuitive user interface which offers the most important functions (support for different applications, user-specific settings).

The DMA instrument conducts accurate measurements and provides reproducible data.

It records data over wide ranges of temperature including upper temperatures where materials become soft and deform and lower temperatures reaching minus 100 degrees Celsius and below.

It characterizes material properties beyond its glass transition temperature.

It offers a wide frequency range.

It is able to apply strong forces.

The DMA instrument has an attractive purchase price, low operational costs, and low nitrogen consumption if a cooling system is used.

The DMA instrument generates low noise levels.

The DMA instrument performs measurements which comply with international standards and guidelines.

The DMA instrument is safe to use.

Figure 6.1 List of customer needs based on competitive benchmarking[176]

6.2 **Development of product platforms**

Development of product platforms describes a conceptual approach involving a development process in which a group of related products is derived from one technology platform. Many benefits are addressed to product platforms, of which some of them are reduced costs in development and production and a greater flexibility to satisfy the needs of customers. Other benefits are the possibility of sharing production capacities across many product groups and a reduced system complexity and development time as it was described by SIMPSON/SIDDIQUE/JIAO.[177] A detailed description of product platform development can be seen in chapter 2.5.5.2.

[176] Own illustration, Customer needs derived from a DMA study of polycarbonate samples in 2010.
[177] Simpson, Siddique and Jiao, 2006, pp. 2-10

This chapter is also related to the concept of product platform development and particularly points out two scenarios which have been considered for the special case of Anton Paar. These two scenarios have been selected based on the past development of Anton Paar´s product portfolio, whereas the current product strategy of existing competitors also has been taken into account. The two scenarios, to which further considerations are related to, are as follows:

- Scenario 1: Expansion of the product range
- Scenario 2: Development of a new thermal analysis platform

6.2.1 **Expansion of the product range**

The first scenario considers a thermal analysis instrument which is based on the existing rheometer technology. Therefore, the existing rheometric instrument of Anton Paar might be redesigned to a modular concept. This concept comprises all functions and features of the rheometer that have been available up to now and additionally includes all types of loadings and clamping fixtures of a standard DMA device. In doing so, the rheometer would also be capable of measuring different modes for different sample geometries which are in particular single cantilever, dual cantilever, tension, compression, three-point bending and shear (also shown in chapter 3.2.4).

Figure 6.2 illustrates the first scenario where the existing rheometer platform is used to develop a new analytical instrument which comprises functionalities of a rheometer as well as full functionality of a DMA device. Platform A hereby represents any number of other product platforms which currently exist in the product range of Anton Paar, like for example the product platform for density and concentration measurements. The positioning of the new instrument within the DMA market and how the market is currently facing price competition is explained in detail in chapter 6.3.

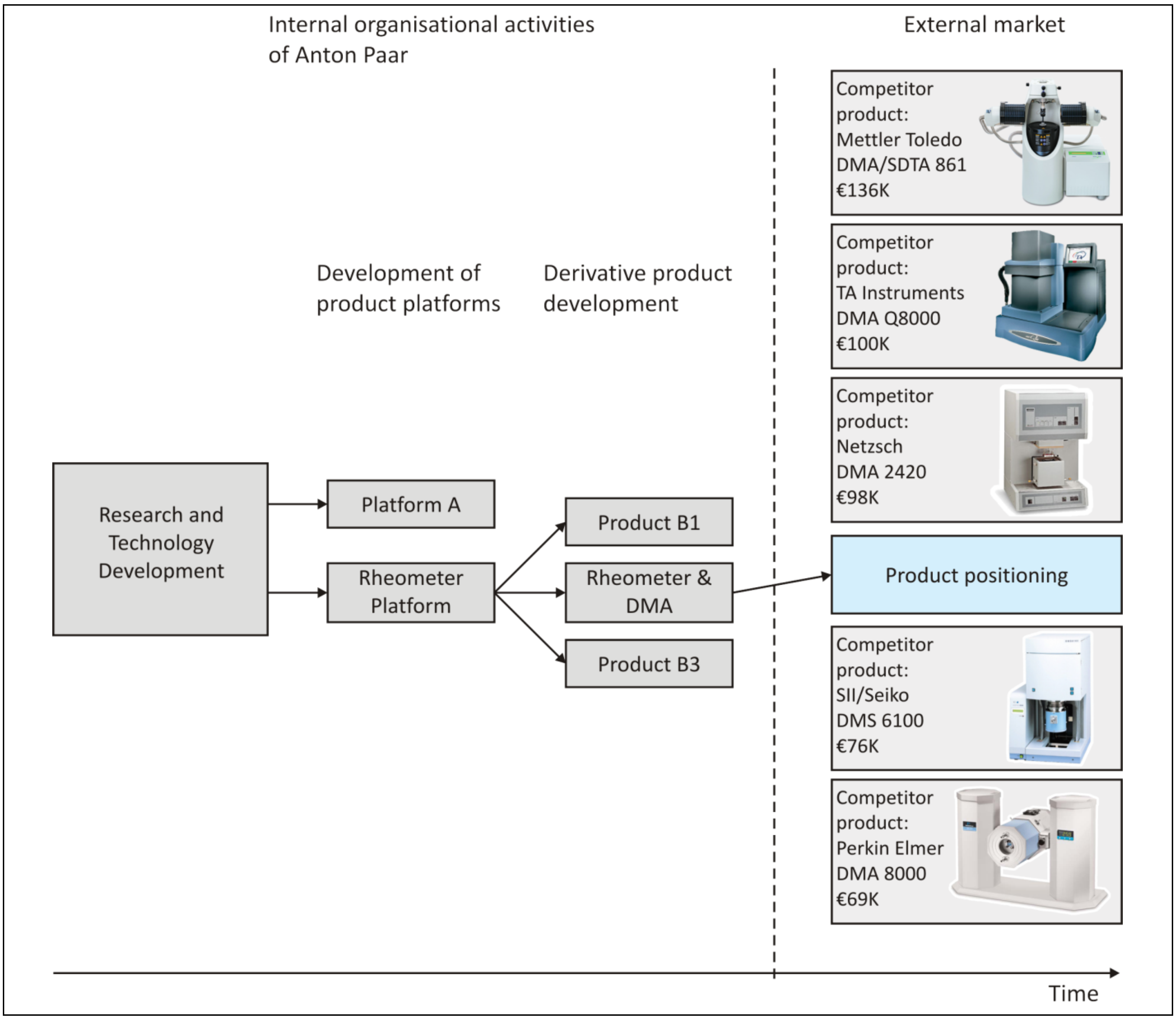

Figure 6.2 Illustration of scenario 1 – Use of rheometer platform for development of new instrument with combined functionality of a rheometer and dynamic mechanical analyser[178]

6.2.2 Development of a new thermal analysis platform

In scenario 2, the establishment of a new thermal analysis platform is being considered. The thermal analysis technology might be introduced as a completely new platform among all platforms currently existing in the product range of Anton Paar. This means that research and development activities focus on development of a thermal analysis product platform from that a group of thermal analysis instruments can be derived in future. However, at the beginning it might be more a question of developing one product with dynamic mechanical analysing functionality because the research and development capacities of the company are limited. But in the long-term perspective also the development of other thermal analysis instruments may be a useful approach to expand in the related market.

[178] Own illustration, Adapted from Trott, 2004, p.358

Figure 6.3 shows how a new attempt will be made to set up a thermal analysis platform. Research and development functions hereby have to establish a new technology which is introduced in the portfolio of Anton Paar. Based on the new platform, a stand-alone DMA instrument which particularly satisfies the customer needs is designed. In this scenario, Anton Paar´s DMA instrument would face direct competition with other companies as the DMA instrument would be of similar engineering concept to the currently existing products on the market. A differentiation to the existing products can be achieved by improved technical characteristics, lower price and a greater user convenience. In Figure 6.3, any kind of other analytical instrument that may be derived in future from the thermal analysis platform is represented by the element indicated with "Product B2".

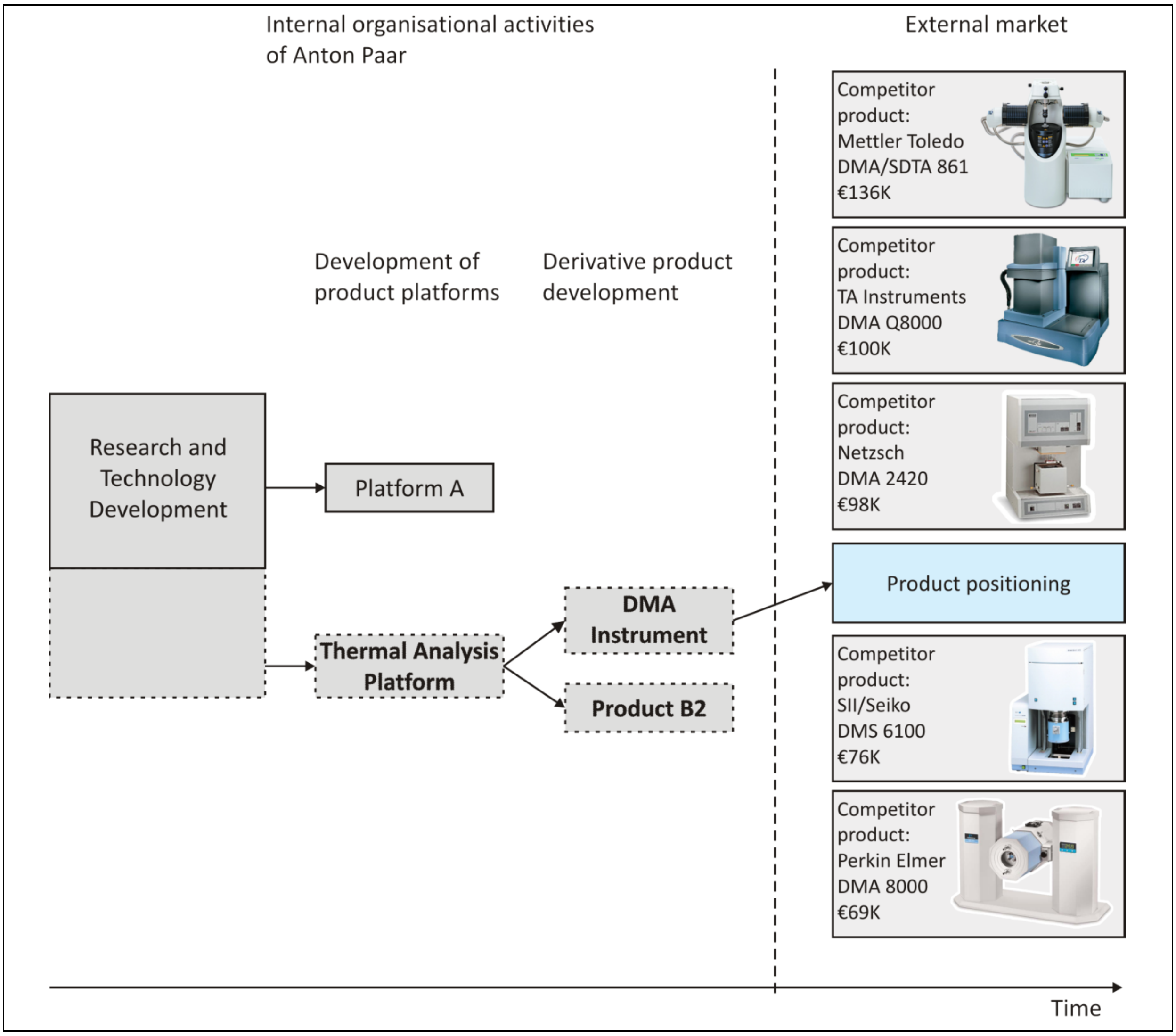

Figure 6.3 Illustration of scenario 2 – Development of new thermal analysis platform and derivation of whole product group[179]

[179] Own illustration, Adapted from Trott, 2004, p.358

6.3 Position in the market

Deeper analysis of the present situation on the market is an important step in the positioning strategy. Product positioning is referred to the way customers perceive a product relative to the competitor´s products. In many cases customers differentiate the products, among different other attributes, by their price and quality.[180]

The positioning study which was conducted within the course of this work was focused on the current pricing situation on the market. For this purpose, information has been gathered about the list prices of the products from the five main players on the market. This information has been obtained from both a subsidiary of Anton Paar where price estimations of the competing products already have been available and from price information directly available from the companies.

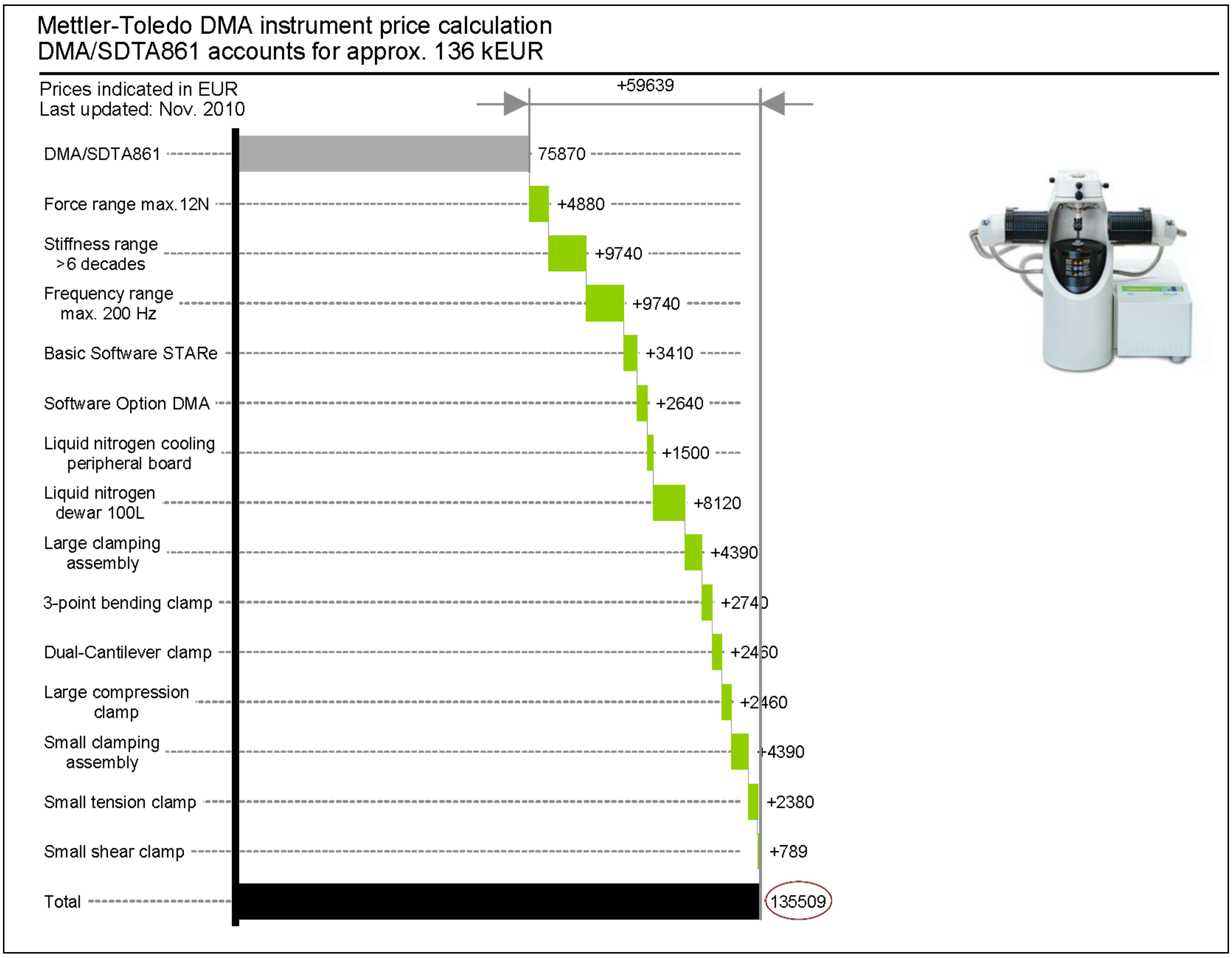

Figure 6.4 Price calculation of DMA instrument from Mettler-Toledo[181]

[180] Trott, 2004, pp. 356-361

[181] Own illustration, Data aggregated from Mettler-Toledo, 2010, pp. 2-6

A product price calculation of one competitor´s product is shown exemplarily in Figure 6.4. The DMA instrument from Mettler-Toledo has been demonstrated as an example as it was the product with the highest price. A closer look on the indication of prices of the product revealed some interesting aspects regarding the pricing strategy of this company. Nearly half of the total product price is accounted for optional accessories. Furthermore, it can be seen that their pricing structure is based on a modular concept which means that every single additional feature has been mentioned separately. Technical specifications regarding all DMA instruments which have been examined are shown in appendix A.

Competing with other products

TROTT described that competing products are also compared to each other whereas customers recognise objective and subjective factors.[182] The aim of this part was to compare the existing rheometer including DMA functionality with other DMA instruments on the market.

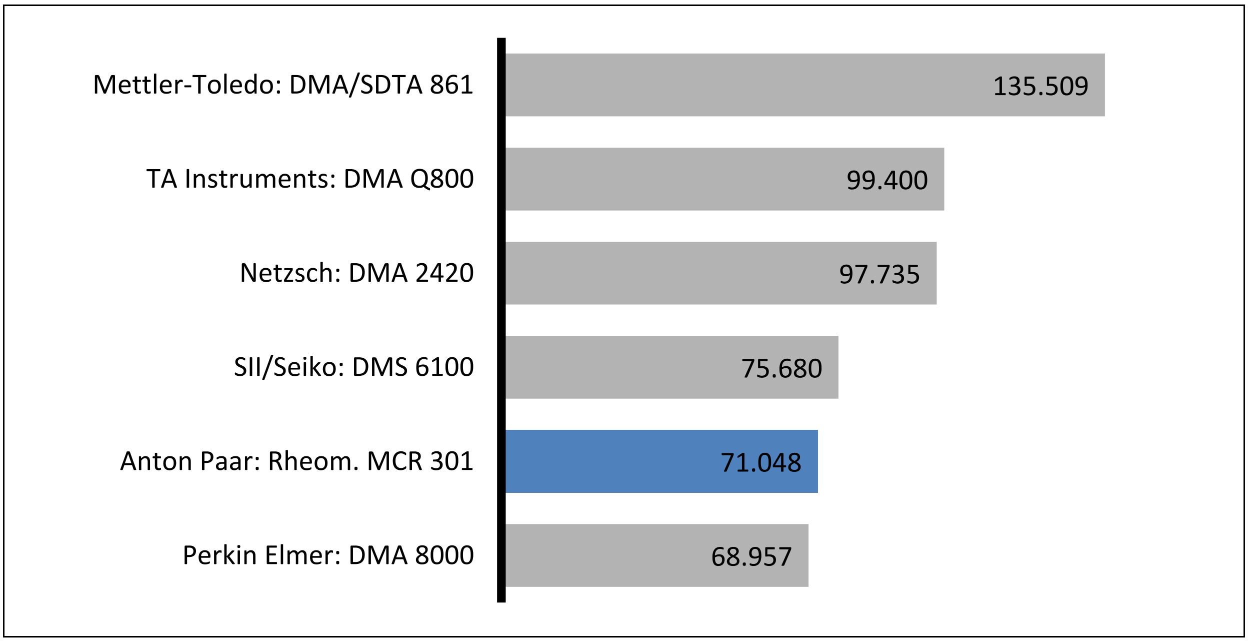

Figure 6.5 Price comparison of DMA instruments as of November 2010, Prices indicated in Euro[183]

As shown in Figure 6.5, the rheometric instrument of Anton Paar is in the lower price segment as compared to five other DMA instruments from the main competitors. However, this comparison has been made with the premise that not all types of loadings are currently covered by the rheometer MCR 301. The comparison also leads to an important insight

[182] Trott, 2004, pp. 360-362

[183] Own illustration, Data aggregated from list price information directly from the companies, Data aggregated also from market research study by subsidiary of Anton Paar, 2010

regarding the price range of all products. By comparing the instrument where the highest price was reported with that one where the lowest price was offered it can be seen clearly that the cheaper device accounts less than half of the price of the high priced instrument. Additionally must be mentioned that in this part no technical specifications of the products have been compared with each other.

6.4 Final results and recommendations

After having considered two different scenarios for product development strategies in chapter 6.2, the pricing competition among companies offering DMA instruments had been analysed subsequently. The advantages and disadvantages of both scenarios are compared in this chapter. For that purpose scenario 1 representing the rheometric instrument with combined DMA functionality is studied in detail firstly. In a second step, the advantages and disadvantages of scenario 2 will be compared. The strategic deliberations in this chapter always have been related to the perspective of Anton Paar.

6.4.1 Advantages of a combined rheometer & DMA instrument

The left side of Table 6.1 shows the advantages of scenario 1. It is assumed that the new concept of combining a rheometer and a thermal analysis instrument in one device will be its unique selling proposition on the market. There is no other DMA instrument that offers a combination of rheometry and thermal analysis currently on the market nor is it known that any other company is planning to introduce an analytical instrument with a similar concept. This could help to gain competitive advantage as the comprehensive product functionality might be a crucial differentiation characteristic to other DMA instruments.

The current available rheometer of Anton Paar can be used as a technology platform from which the design of a new product might be derived. That means, in turn, that the effort for research and development activities would be lower compared to scenario 2. Furthermore, existing technological know-how related to product technology can have a positive impact on reducing the development time. Finally, the costs might also be considered in relation to the whole product development process seen as a single investment from the company´s perspective. According to NEEDLES/POWERS/CROSSON, the return on investment (ROI) is defined as the ratio of operating income to assets invested and helps to explain changes in return on investment also for a single investment centre.[184] Hence a lower capital investment during a product development process would lead to a higher return on investment.

[184] Needles, Powers and Crosson, 2008, p. 1152

6.4.2 **Disadvantages of a combined rheometer & DMA instrument**

A basic disadvantage of the related scenario would be a higher expected target price. It is assessed that the higher complexity of the device as it is a combination of two single devices would lead to a higher price. Hence the company will even face a fiercer competition in the DMA market.

The aspect of developing this new market might also become more disadvantageous because more work to convince the customers of the new product features would be needed. The disadvantages are also mentioned briefly on the right side of Table 6.1.

Table 6.1 Comparison of advantages and disadvantages for a combined rheometer & DMA instrument[185]

Advantages	Disadvantages
• Combination of rheometry & thermal analysis • Differentiation from existing competition • R&D effort ↓ • Existing technological know-how • ROI ↑ (single project)	• Higher target price • Relatively new market

6.4.3 **Advantages of a stand-alone DMA instrument**

The advantages and disadvantages of scenario 2 which considers a completely new designed DMA instrument are analysed in this step. Table 6.2 gives an overview of all aspects which have been identified for a stand-alone DMA instrument.

A new DMA instrument including clamping fixtures for all sample geometries is a similar approach which also has been applied by other companies in the past. The key issue here is to successfully differentiate the new product from the existing ones on the market. Based on past experience of Anton Paar about product development processes, it is also expected to get out a well-designed product at the end of the product development process which particularly addresses the needs of current DMA customers. And as the new product is

[185] Own illustration

especially designed for DMA applications, the system complexity would be reduced and hence a lower target price is assessed to be reached.
The overall usability is another aspect which is taken into account. Considering the combined solution of a rheometer with complete DMA functionality, a modification of the system setup and reconfiguration activities would be needed in order switch between rheometry and DMA measurements. When this reconfiguration effort is compared with the reduced handling effort for the stand-alone DMA instrument, the latter solution would be preferable.

6.4.4 Disadvantages of a stand-alone DMA instrument

The introduction of a new DMA instrument in the current portfolio of Anton Paar also means that a product development process must be initiated for a new technology platform. In this case, knowledge about the DMA technology as well as information and experience about the latest devices on the market must be gained in advance. Not only this knowledge transfer process but also the whole product development process would need more time till a finished product can be launched on the market. This leads to the assumption that time to market and costs become far more critical.

Finally, the internal competition of the new DMA instrument with other analytical instruments from Anton Paar is being considered. As shown in chapter 4.4, the current available rheometer from Anton Paar already encompasses some of the DMA measuring modes. In the case of introducing a stand-alone DMA instrument it would compete against the solution with rheometric instrument equipped with DMA accessories. The customer would have to choose between two similar solutions within the product range of Anton Paar which neither would be an optimal solution.

Table 6.2 Comparison of advantages and disadvantages for a stand-alone DMA instrument[186]

Advantages	Disadvantages
• Target price expected to be lower • Specialised instrument designed for DMA applications • No assembly or modifications on instrument	• Long-term process of product development • Higher costs in R&D • Competition against Anton Paar´s own products

[186] Own illustration

6.4.5 **Recommendations**

On the basis of information which has been collected during this work and considering the advantages and disadvantages from the previous chapters, a recommendation for Anton Paar can be made now.

In view of the current situation of Anton Paar, recommendation is given to expand the existing rheometer platform by a new instrument which combines rheometry and dynamic mechanical thermal analysis methods (see scenario 1 described in chapter 6.2.1). The combination of two measurement methods in one instrument would clearly differentiate the product from others in the market. Additionally, the aspect of internal competition of a stand-alone DMA instrument against the existing rheometer series from Anton Paar is also of considerable relevance. However, a strategic direction of the company towards development of a stand-alone instrument for thermal analysis might also be a reasonable alternative in the long-term perspective.

7 Conclusion

The aim of this work was to investigate product development strategies for Anton Paar which will form the basis for future management decisions.
Many different applications of thermal analysis have been identified in the first part of the work. The most important applications of thermal analysis methods are related to the determination of material properties in the field of polymers, pharmaceuticals, foods, biomaterials and inorganic compounds.

The core competencies of Anton Paar as well as the company´s business environment have been analysed in the second part. This shows that a small overlap of the dynamic mechanical analysis (DMA) method with one product segment of Anton Paar already exists. A consideration of all industries relevant for thermal analysis applications came to the result that these industries are also served by Anton Paar. Hence, entering a market whose characteristics are already known would bear lower risks for the company. Considering the company´s current sales and service network, it can be mentioned that no major changes have to be made as the company is already well positioned at an international level.

In the course of this work, the DMA technology has been selected as target market. As no precise data for the DMA market are currently available, the market research study was focused on the overall thermal analysis market. In this context, the total market size for thermal analysis instruments is assessed to have reached approximately US $ 330 million as of 2009. The Asia-Pacific region has revealed a potential growth field for thermal analysis equipment. Additionally, the importance of the pharmaceutical science in the field of thermal analysis has been pointed out in this study.
This work also provided a deeper understanding of the current competitive situation. Many companies operating in the thermal analysis business sector have been identified, but the focus has been given to the five major players. It is estimated that these five companies have a cumulated market share of approximately 83% of the total market. The rivalry on the DMA market is also assessed to be high as there are many companies currently operating in this field and it can be expected that also the companies with smaller market share continue to improve the performance of their products at competitive prices.

In order to conclude the work, a recommendation can be given towards an expansion of the rheometer platform. Implicitly, this point of view considers the advantages of the extended functionality of the product as well as less resources needed for new product development. It also must be noted that the alternative way to develop a stand-alone DMA instrument might be a useful and interesting approach for the future.

List of Figures

List of Tables

List of Abbreviations

CEO	Chief executive officer
CNC	Computer numerical control
CTE	Coefficient of thermal expansion
DEA	Dielectric analysis
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
DTA	Differential thermal analysis
e.g.	Exempli gratia; Latin abbreviation of "for example"
EGA	Evolved gas analysis
GmbH	Gesellschaft mit beschränkter Haftung
ICTA	International Confederation for Thermal Analysis and Calorimetry
Inc	Incorporation
I.V.	Intravenous
LLW	Low-level waste
LPDS	Lean product development system
Ltd	Limited; Limited company
LVDT	Linear variable differential transformer
µ/n – TA	Micro/Nano - thermal analysis
MCR	Modular compact rheometer
n.d.	No date
NPD	New product development
p.	Page
pp.	Pages
PCB	Printed circuit board
TA	Thermal analysis
T_c	Crystallisation temperature
TD	Thermodilatometry
T_m	Melting temperature
TMA	Thermomechanical analysis
TG	Thermogravimetry
T_g	Glass transition temperature
TGA	Thermogravimetric analysis
TOA	Thermo-optical analysis
R&D	Research and Development
ROI	Return on investment
SCF	Solid circular fixture
SER	Sentmanat extension rheometer
SMT	Surface mount technology
SRF	Solid rectangular fixture
UK	United Kingdom
US	United States
UXF	Universal fixture

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Appendices

Appendix A: Company fact-sheet

Appendix B: Price calculation of different DMA instruments

Appendix A: Company fact sheet

Competitive Analysis for Anton Paar GmbH
Thermal Analysis Industry

last updated: 21.10.2010

Company	Currencies	Sales	Business Units / Divisions / Product Groups		
TA Instruments		in figures:	**Thermal Analysis**	**Rheology**	**Calorimetry**
Waters Corporation	Mio US-Dollar 2009 *	147,6	n.a.	n.a.	n.a.
 New Castle, Delaware USA	Mio US-Dollar 2008	165,7	Thermal Analysis instruments for material characterization	Rheometry instruments for characterization of flow properties of materials	Calorimetry and Microcalorimetry instruments for material characterization
	Increase/Decrease in % 2009 vs. 2008	-11%			
www.tainstruments.com			FY ended: Dec, 31		
Global Footprint	Employees	Locations	Manufacturing facilities	R&D	Service
Annotations:	total:	worldwide:			
	n.a.	Waters operates 23 United States facilities and 77 international facilities, including field offices.	Thermal analysis products are manufactured at New Castle, Delaware facility. Rheometry products are manufactured at New Castle, Delaware and Crawley, England facilities.	approx. 100 employees **	TA Instruments service sales represented approx. 35% (Mio $ 38,24) of total net sales in 2009
Sources:	TA Instruments webpage * Total net sales included TA Instruments' product sales and service sales. This was based on company information, available in the Annual Report 2009. Retrieved October 21, 2010, from http://phx.corporate-ir.net/phoenix.zhtml?c=77764&p=irol-reportsAnnual ** Based on Anton Paar internal information: market overview thermal analysis				

Note: n.a. = data not available

TA Instruments

Further Information	
Termal Analysis Products	
DTA	
DSC	3 DSC (robotic autosampler and measuring cell for accurate parameter compensation are optional available)
TG/TGA	3 TGA (with IR-furnance for high heating rates, vacuum operation, high-sensitive thermobalance), 1 TGA-HP (for high-pressure, ultra-high vacuum, and high-temperature range)
TMA	1 TMA
DIL	
DMA	2 DMA (with direct-drive linear motor, air bearings)
DEA	
EGA	
Simultaneous TGA-DSC	1 TGA-DSC (with horizontal balance and furnance)
Others	2 Vapor Sorption Analyzer (for controlled temperatrue and humidity conditions)

Technical Specification:

TA Instruments	Q800	**TA Instruments**	RSA III
			
Measuring principle	DMA	Measuring principle	
Temperature range	-150°C ... 600°C	Temperature range	-150°C ... 600°C
Temperature accuracy	0.1 K	Temperature accuracy	0.1 K
Frequency range	0.01 ... 200 Hz	Frequency range	0.00002 ... 80 Hz
Force range	0.0001 ... 18 N	Force range	0.001 ... 35 N
Displacement range	± 0.5 ... 10000 µm	Displacement range	± 0.5 ... 1500 µm
Displacement resolution	n.a.	Displacement resolution	n.a.
Tan delta range	n.a.	Tan delta range	n.a.
Stiffness range	n.a.	Stiffness range	n.a.
Modulus range	10^3 to $3x10^{12}$ Pa	Modulus range	10^3 to $3x10^{12}$ Pa

Note: n.a. = data not available

TA Instruments

Competitive Analysis for Anton Paar GmbH
Thermal Analysis Industry

last updated: 20.10.2010

Company	Currencies	Sales	Business Units/Divisions		
Mettler-Toledo		in figures:	**Laboratory Instruments**	**Industrial Instruments**	**Retail Weighing Solutions**
International Inc.	Mio US-Dollar 2009	1.728,9	% of net sales in 2009: 46%	% of net sales in 2009: 42%	% of net sales in 2009: 12%
 Greifensee/Nanikon, Switzerland	Mio US-Dollar 2008 Increase/Decrease in % 2009 vs. 2008	1.973,3 -12%	Laboratory Balances, Pipettes, Analytical Instruments (Titrators, Thermal analysis systems, pH meters), Laboratory Software, Automated Chemistry Solutions, Process Analytics	Industrial Weighing Instruments, Industrial Terminals, Transportation and Logistics, Vehicle Scale Systems, Industrial Software, Product Inspection	Standalone Scales, Networked Scales and Software, Retail Software (item and inventory management)
www.mt.com			FY ended: Dec, 31		
Global Footprint	Employees	Locations	Manufacturing facilities	R&D	Service
Annotations:	total:	worldwide:			
	approx. 10400	approx. 24	in China, Germany, Switzerland, United Kingdom, United States	approx. 5,2% of net sales in 2009, approx. 1000 employees	approx. 25% of net sales in 2009
Sources:	Mettler-Toledo Annual Report 2009				

Mettler-Toledo

Further Information	
Termal Analysis Products	
DTA	
DSC	1 DSC 1 Flash DSC (high heating- and cooling rates) 1 HP DSC (high pressure)
TG/TGA	
TMA	2 TMA-SDTA
DIL	
DMA	1 DMA-SDTA
DEA	
EGA	
Simultaneous TGA-DSC	1 TGA-DSC (Optional Accessories available: mass spectrometer, FTIR spectrometer, and sorption analyzer)
Others	

Technical Specification:

Mettler-Toledo	DMA/SDTA 861e
	
Measuring principle	DMA
Temperature range	-150°C ... 500°C
Temperature accuracy	0.5 K
Frequency range	0.001 ... 1000 Hz*
Force range	0.001 ... 40 N
Displacement range	± 1600 µm
Displacement resolution	0.6 nm
Tan delta range	0.0001 ... 100
Stiffness range	10 ... 10^8 N/m
Modulus range	n.a.

* Max. frequency may vary depending on deformation mode.
Note: n.a. = data not available

Mettler-Toledo

Competitive Analysis for Anton Paar GmbH
Thermal Analysis Industry

last updated: 21.10.2010

Company	Currencies	Sales	Business Units/Divisions		
Perkin Elmer		in figures:	**Human Health Segment**	**Environmental Health Segment**	
Inc.	Mio US-Dollar 2009	1.812,0	736,5	1.075,7	
 Winter Street, Waltham USA	Mio US-Dollar 2008 Increase/Decrease in % 2009 vs. 2008	1.960,0 -8%	Diagnostics Market: early detection for genetic disorders, medical imaging Research Market: reagents, liquid handling and detection technologies	Environmental Market: Systems and technologies for environmental testing (e.g. water quality monitoring) Safety & Security Market: Dangerous materials detection systems, sensors and detectors for environmental applications Industrial Market: Analytical instrumentation, detectors, and sensors for quality and industrial process control Laboratory Services Market: Support and services for laboratries	
www.perkinelmer.com			FY ended: January, 3		
Global Footprint	Employees	Locations	Manufacturing facilities	R&D	Service
Annotations:	total:	worldwide:			
	approx. 8200	150 countries throughout the Americas, Europe, Asia and Africa	n.a.	5,9% of sales in 2009	n.a.
Sources:	Perkin Elmer annual report 2009				

Note: n.a. = data not available

Perkin Elmer

Further Information	
Termal Analysis Products	
DTA	
DSC	4 DSC (conventional, instruments with fast scanning rates, optional photocalorimetry available)
TG/TGA	2 TGA
TMA	
DIL	
DMA	1 DMA (DMA+TMA)
DEA	
EGA	
Simultaneous TGA-DSC	
Others	FTIR spectrometer, Gas Chromatograph/Mass spectrometer, spectroscopy

Technical Specification:

Perkin Elmer	DMA 8000

Measuring principle	DMA + TMA
Temperature range	-190 ... 600°C
Temperature accuracy	n.a.
Frequency range	0.001 ... 300 Hz
Force range	0.002 … 10 N
Displacement range	±1000 µm
Displacement resolution	1 nm
Tan delta range	0.00001 … ?
Stiffness range	200 ... 10^8 N/m
Modulus range	10^3 to 10^{16} Pa

Note: n.a. = data not available

Perkin Elmer

Competitive Analysis for Anton Paar GmbH
Thermal Analysis Industry

last updated: 21.10.2010

Company	Currencies	Sales	Business Units/Divisions		
Netzsch		in figures:	**Pumps**	**Grinding & Dispersing**	**Analyzing & Testing**
Group	Mio Euro 2009	280,7	152,5	77,5	49,8
NETZSCH  Selb, Bavaria Germany	Mio Euro 2008	292	Pumps and pump systems, Joint systems for pumps	Grinding systems for wet and dry grinding, Mixing and dispersing systems for solids and suspensions	Instruments and systems for thermal analysis
	Increase/Decrease in % 2009 vs. 2008	-4%			
www.netzsch.com			FY ended: June, 30		
Global Footprint	Employees	Locations	Manufacturing facilities	R&D	Service
Annotations:	total:	worldwide:			
	2211	in Europe, Asia, North America, South America	n.a.	n.a.	n.a.
Sources:	Netzsch group webpage Consolidated financial statement, fiscal year 2008/2009				

Note: n.a. = data not available

Netzsch

Further Information	
Termal Analysis Products	
DTA	1 DSC/DTA
DSC	5 DSC (incl. high temperature range, high pressure range)
TG/TGA	6 TGA (Thermo-Microbalance and -Nanobalance)
TMA	3 TMA (of which 2 TMA are phase-out models)
DIL	5 DIL (incl. vacuum-tight, horizontal application)
DMA	1 DMA
DEA	2 DEA
EGA	3 EGA (incl. Fourier Transform-Infrared Spectrometer (FTIR))
Simultaneous TGA-DSC	4 TGA-DSC (incl. high temperature range)
Others	1 MMC (Multiple Mode Calorimeter) 3 ARC (Adiabatic Reaction Calorimeter) 6 Thermal Diffusivity and Conductivity instruments (Flash apparatus, heat flow meter, thermal conductivity tester) 3 Refactory Testing instruments (Refractoriness under load, Creep in compression, Modulus of Rupture)

Technical Specification:

Netzsch	DMA 242 C
Measuring principle	DMA
Temperature range	-170°C ... 600°C
Temperature accuracy	± 1 K
Frequency range	0.01 Hz ... 100 Hz
Force range	max. 16N; max. 8 N static and max. +/- 8 N dynamic
Displacement range	249 µm
Displacement resolution	0.5 nm
Tan delta range	0.00006 ... 10
Stiffness range	n.a.
Modulus range	10^3 Pa ... 10^{12} Pa

Note: n.a. = data not available

Netzsch

Competitive Analysis for Anton Paar GmbH
Thermal Analysis Industry

last updated: 11.11.2010

Company	Currencies	Sales	Business Units / Divisions / Product Groups					
SII NanoTechnology Inc.		in figures:	**Thermal Analysis**	**Scanning Probe Microscope (SPM)**	**XRF Analysis**	**ICP Analysis**	**Focused Ion Beam (FIB)**	**Molecular Imaging**
Seiko Holdings Corporation	Mio Yen 2009 *	13.930	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Chiba, Japan	Mio Yen 2008	n.a.	High performance Thermal Analysis System including heat flux DSC, horizontal dual beam type TG/DTA and high reliability TMA and DMA products	High-resolution and high-precision scanning probe microscopes	Energy dispersive fluorescent X-ray Analyzers	ICP optical emission spectrometer (ICP-OES) and ICP mass spectrometer (ICP-MS)	Combined scanning electron and focused ion beam workstations	Molecular Imaging systems including PET, SPECT and CT (Computed Tomography) techniques
	Increase/Decrease in % 2009 vs. 2008	n.a.						
www.siint.com			FY ended: February					

Global Footprint	Employees	Locations	Manufacturing facilities	R&D	Service
Annotations:	total:	worldwide:			
	540 (including temporary & part time employee)	Mainly offices in Japan; Subsidiaries in China, USA, and Germany	n.a.	n.a.	New worldwide sales and service network since January 01, 2007 after former cooperation with Perkin Elmer
Sources:	SII webpage * Consolidated annual sales figures for FY 2009. Retrieved November 11, 2010, from http://www.siint.com/en/company/aboutkgk/index.html				

Note: n.a. = data not available

Seiko

Further Information	
Termal Analysis Products	
DTA	
DSC	2 DSC (High Sensitivity DSC), 1 DSC (normal - 6000series)
TG/TGA	1 TGA/DTA (Simultaneous TGA/DTA with µg level weight changes), 1 TGA/DTA (normal - 6000series)
TMA	1 TMA (High sensitivity TMA, optional automatic cooling unit), 1 TMA (with exchangeable furnance - 6000series)
DIL	
DMA	1 DMA (normal - 6000series)
DEA	
EGA	
Simultaneous TGA-DSC	
Others	

Technical Specification:

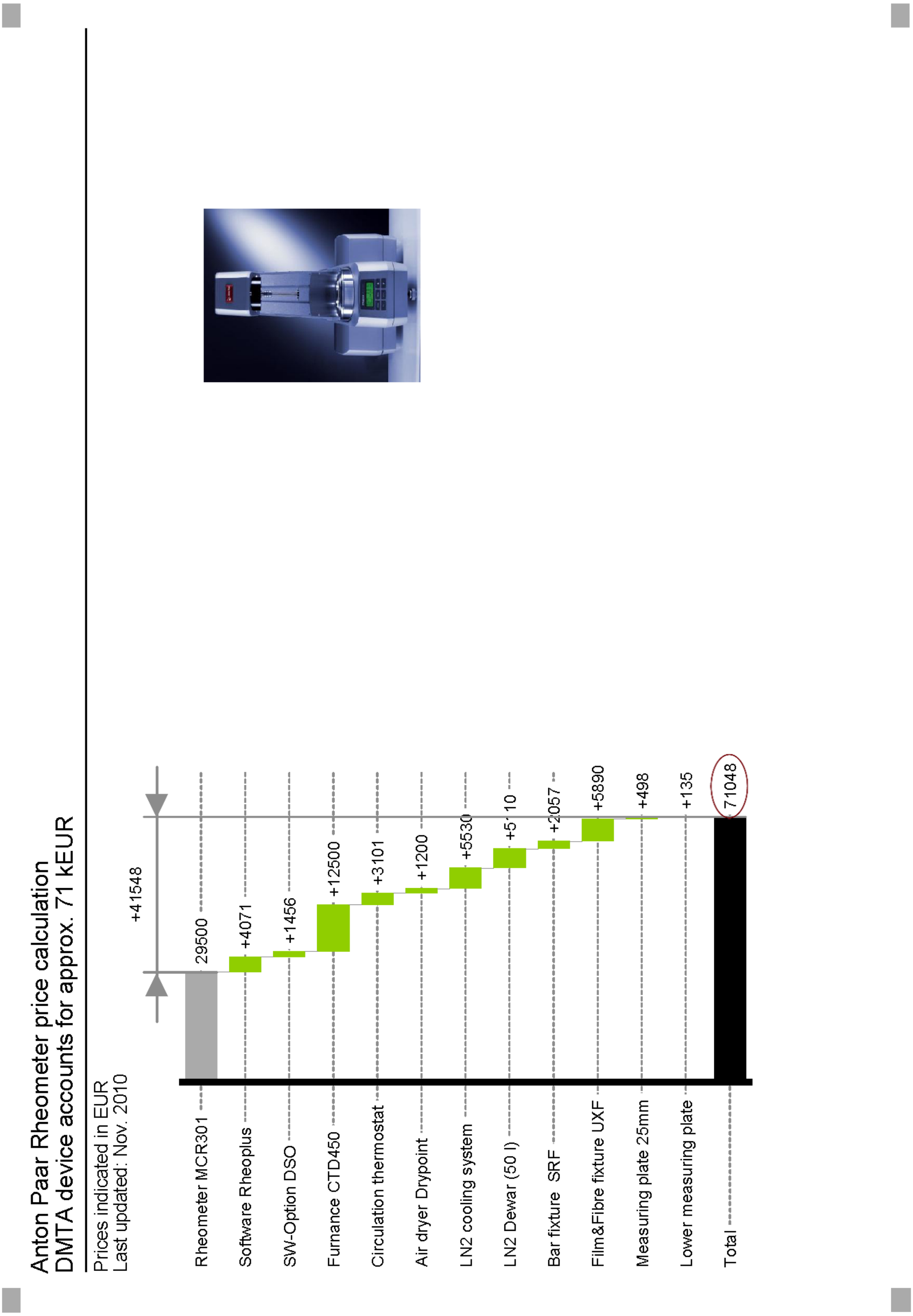
SII NanoTechnology	EXSTAR DMS6100

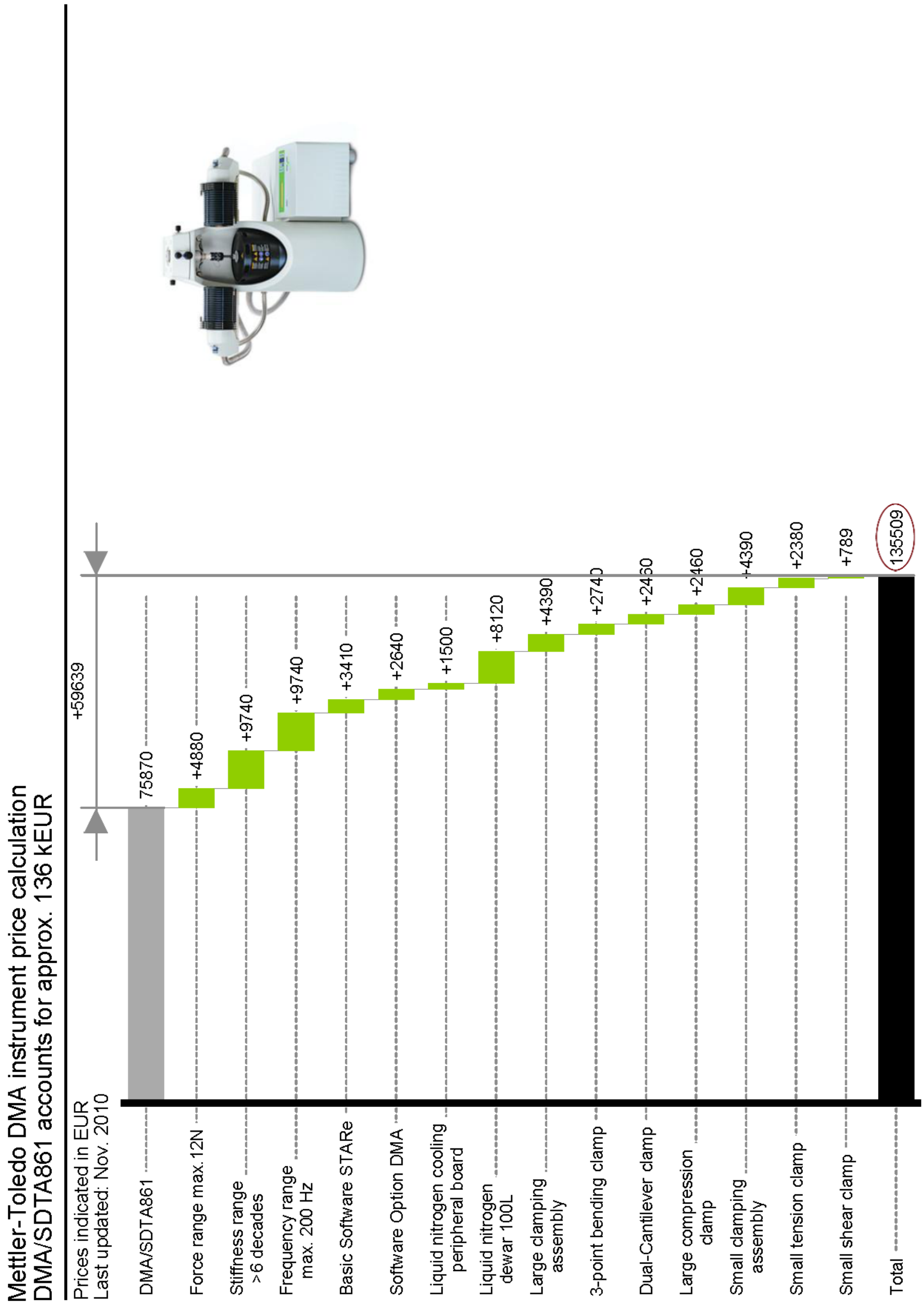
Measuring principle	DMA
Temperature range	-150 ... 600°C
Temperature accuracy	n.a.
Frequency range	0.01 ... 200Hz
Force range	n.a.
Displacement range	n.a.
Displacement resolution	n.a.
Tan delta range	n.a.
Stiffness range	n.a.
Modulus range	10^3 Pa ... 10^{12} Pa

Note: n.a. = data not available

Seiko

Appendix B: Price calculation of different DMA instruments

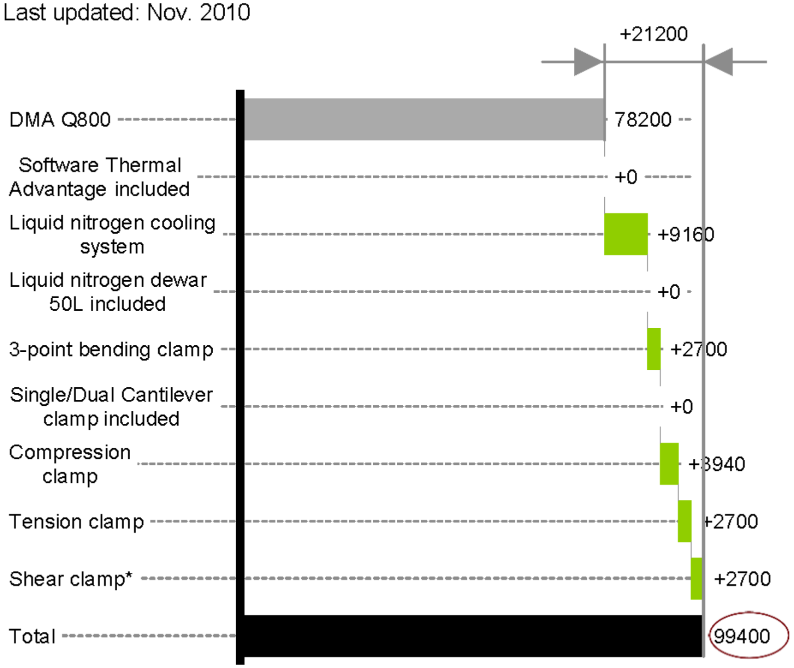

Anton Paar Rheometer price calculation
DMTA device accounts for approx. 71 kEUR
Prices indicated in EUR
Last updated: Nov. 2010
Rheometer MCR301
Software Rheoplus
SW-Option DSO
Furnance CTD450
Circulation thermostat
Air dryer Drypoint
LN2 cooling system
LN2 Dewar (50 l)
Bar fixture SRF
Film&Fibre fixture UXF
Measuring plate 25mm
Lower measuring plate
Total
29500
+4071
+1456
+12500
+3101
+1200
+5530
+5110
+2057
+5890
+498
+135
71048
+41548



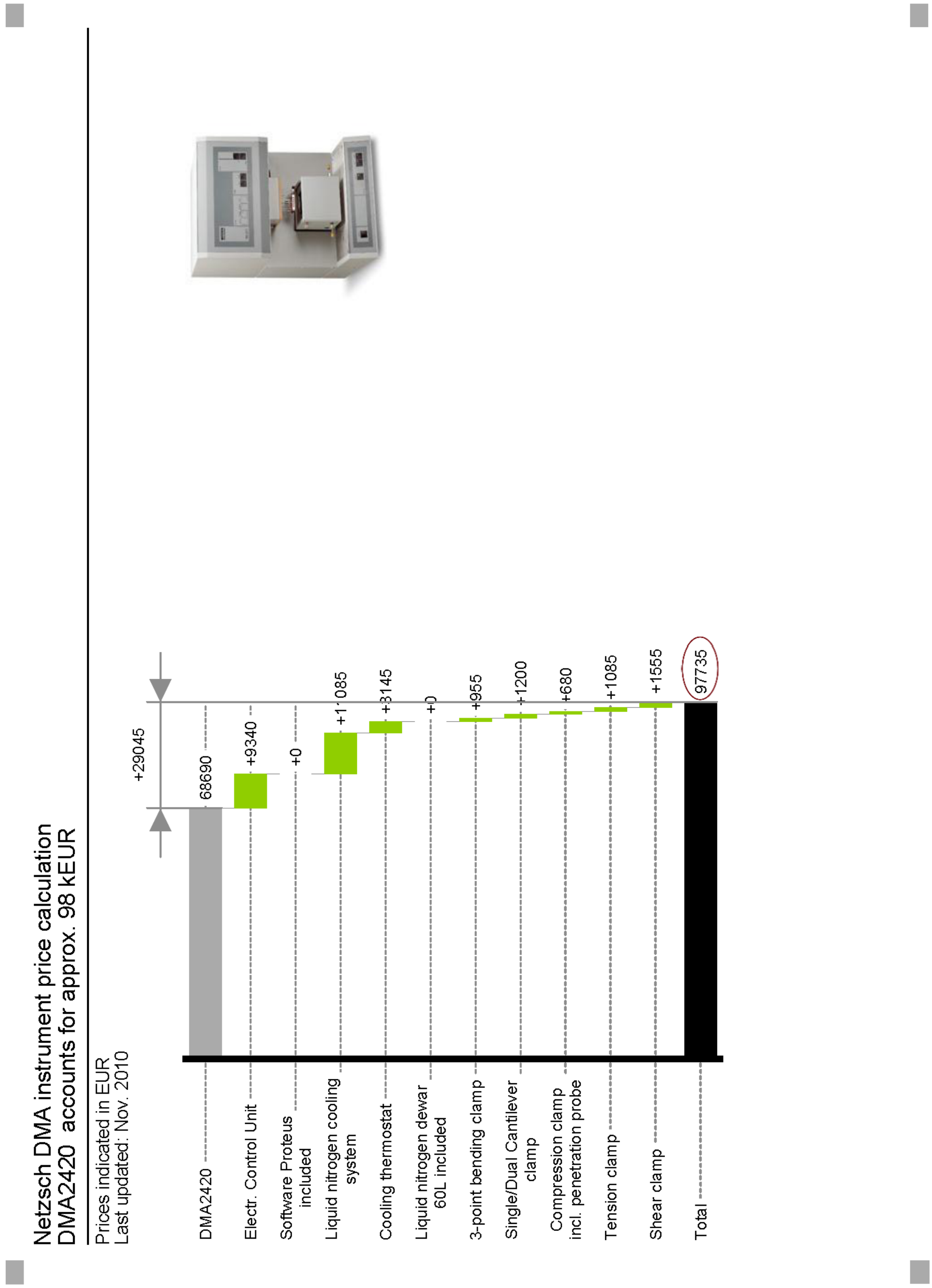
Mettler-Toledo DMA instrument price calculation
DMA/SDTA861 accounts for approx. 136 kEUR
Prices indicated in EUR
Last updated: Nov. 2010
DMA/SDTA861
Force range max.12N
Stiffness range >6 decades
Frequency range max. 200 Hz
Basic Software STARe
Software Option DMA
Liquid nitrogen cooling peripheral board
Liquid nitrogen dewar 100L
Large clamping assembly
3-point bending clamp
Dual-Cantilever clamp
Large compression clamp
Small clamping assembly
Small tension clamp
Small shear clamp
Total
75870
+4880
+9740
+9740
+3410
+2640
+1500
+8120
+4390
+2740
+2460
+2460
+4390
+2380
+789
135509
+59639

TA Instruments DMA equipment price calculation
DMA Q800 accounts for approx. 99 kEUR

Prices indicated in EUR
Last updated: Nov. 2010

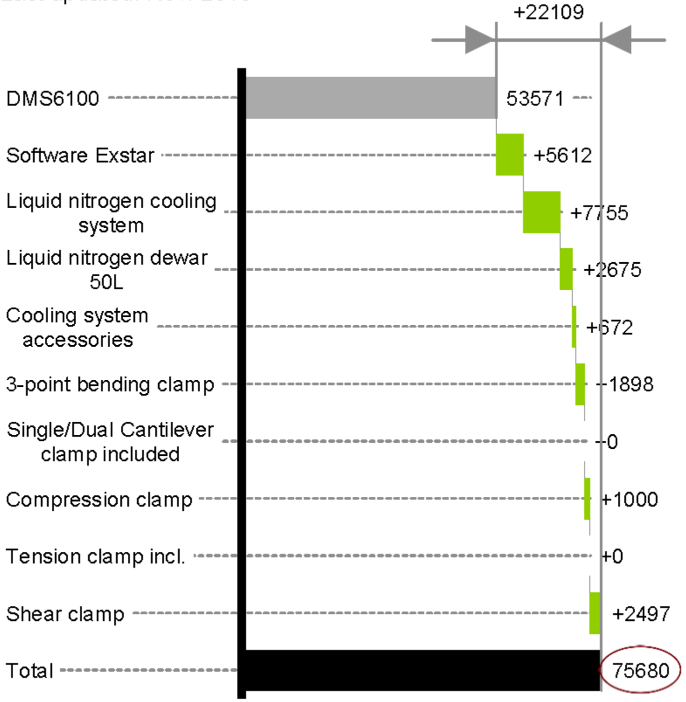


* price estimated


Netzsch DMA instrument price calculation
DMA2420 accounts for approx. 98 kEUR
Prices indicated in EUR
Last updated: Nov. 2010
DMA2420
Electr. Control Unit
Software Proteus included
Liquid nitrogen cooling system
Cooling thermostat
Liquid nitrogen dewar 60L included
3-point bending clamp
Single/Dual Cantilever clamp
Compression clamp incl. penetration probe
Tension clamp
Shear clamp
Total
68690
+9340
+0
+11085
+3145
+0
+955
+1200
+680
+1085
+1555
97735
+29045

SII NanoTechnology DMA instrument price calculation
DMS6100 accounts for approx. 76 kEUR

Prices indicated in EUR
Last updated: Nov. 2010



Perkin Elmer DMA instrument price calculation
DMA 8000 accounts for approx. 69 kEUR

Prices indicated in EUR
Last updated: Nov. 2010