

**COMBINING MULTI-CRITERIA DECISION ANALYSIS WITH INTEGER LINEAL
PROGRAMMING FOR PORTFOLIO SELECTION – CASE OF APPLICATION
THE DAX GERMAN STOCK MARKET**

Marc Schlagenhoff y Thomas Tegethoff

**Trabajo de Grado para optar por el título de Magister en Administración de
Empresas**

Director del Trabajo de Grado: Prof. Juan Felipe Henao Piza

Universidad ICESI

Facultad de Ciencias Administrativas y Económicas

Cali/Bogotá, Mayo 2016

Table of contents

1	Introduction	5
2	The German Stock Markets	10
2.1	<i>German Stock Exchanges</i>	10
2.2	<i>Market Regulation and Segments</i>	10
2.3	<i>Market Efficiency</i>	11
3	Approaches to portfolio selection	12
3.1	<i>Modern Portfolio Theory</i>	13
3.1.1	Limitations of modern portfolio theory	16
3.1.2	Technical criticism	18
3.2	<i>Other Selection Models</i>	19
3.3	<i>MCDA and Optimization</i>	20
4	The MCDA – ILP Model	22
4.1	<i>MCDA criteria</i>	24
4.1.1	Price/Earnings ratio:	24
4.1.2	Dividend Growth	25
4.1.3	Earnings per Share growth	26
4.1.4	Short Term Financial Condition	27
4.1.5	Long Term Financial Condition	28
4.1.6	Return on Equity	28
4.1.7	Dividend Yield	29
4.2	<i>MCDA calculation and result</i>	30
4.3	<i>ILP optimization</i>	33
4.3.1	Primary equation of the proposed model	33
4.3.2	Constraints	34
4.4	<i>Complete Formulation of MCDA-ILP model</i>	36
4.5	<i>Proposed portfolio</i>	37
4.6	<i>Alternative Criteria Weights and Sensitivity</i>	38

5	Comparison of proposed model vs. modern portfolio theory vs. Benchmark DAX 30 and discussion of performance	42
5.1	<i>Conclusion</i>	48
5.2	<i>Limitations of the Proposed Model</i>	49

Resumen

Esta tesis presenta un modelo matemático para facilitar la selección de portafolio de acciones combinando análisis multicriterio y programación lineal integral. Este modelo permite determinar los criterios relevantes para el tomador de decisión, dándole mayor flexibilidad y es más robusto que el modelo clásico de la teoría de portafolio, que sólo evalúa riesgo y rendimiento esperado.

El modelo será aplicado índice DAX 30 de la bolsa de Frankfurt / Alemania y se compara el resultado con dos portafolios seleccionados aplicando la teoría de portafolio. Los resultados de estos portafolios serán comparando posteriormente con el índice DAX 30 de la bolsa de Frankfurt

El resultado obtenido determinó que el modelo MCDA permite construir un portafolio con mayor rendimiento que el mercado (un portafolio basado en el índice el DAX), pero de menor rendimiento que un portafolio basado la teoría de portafolio. Esta pérdida de rendimiento es el resultado de que el enfoque de la decisión se ha ampliado, y no solo toma en cuenta el rendimiento esperado y el riesgo.

Abstract

This thesis proposes a mathematical approach that combines multi-criteria decision analysis and integer linear programming (MCDA-ILP) to facilitate the selection of stock portfolios. The model allows a decision maker to take into consideration not only financial-related criteria, but also corporate-related (managerial and strategic) criteria during the configuration process of the portfolio. This feature grants more flexibility than classic portfolio theory models that only takes into account risk and return criteria and is called also the technical analysis or the fundamental analysis based only corporate information is called therefore value investing theory.

The model is applied to the German stock index DAX 30 and its performance is compared against two portfolios selected using the modern portfolio theory and the market.

Results show that the MCDA-ILP approach leads to the selection of a portfolio that outperforms the market (the DAX), but shows lower performance than a portfolio resulting from pure portfolio theory. This shortfall is due to the broader scope of criteria taken into account in the decision process, rather than exclusively focussing on risk and return.

Palabras Clave

Selección de portafolios

Análisis multicriterio de decisiones

Programación integral entera

Teoría moderna de portafolios

Keywords

Portfolio selection

Multi-criteria decision analysis,

Integer lineal programming

Modern portfolio theory

1 Introduction

Financial markets, and in particular the stock markets, are increasingly important in the current economic environment. In many countries around the world, both in developed and developing countries, public welfare systems are proving incapable of guaranteeing retirement benefits sufficient to maintain acquired living standards for an ever ageing population, while at the same time, inherited fortunes seem to

grow faster than fortunes relying on income from work (Piketty, 2015). These inherited fortunes consist of a variety of asset classes, and participation in enterprises is one of them. Considering that many shares in different enterprises of nearly all industries are traded on the stock exchanges around the world, the stock exchanges offer an opportunity to build diversified portfolios to grow their personal wealth. Moreover, by their nature, investments in stocks can be realized with relatively modest initial values, when compared for instance with investments in real estate, bonds, or participation in closed investment funds and lend themselves well to the implementation of periodical savings plans¹, making them a viable instrument for private investors to invest with the purpose of building up wealth.

Although investment in stocks is in most cases returns a yield superior to bond - investment, this is not always the case. This can be noted when comparing the long-term performance (5, 10 and 20 years) of three major stock indices (DAX, Dow Jones and EUROSTOXX) against fixed-income investments (3% and 5% interest rates). In both cases DAX and Dow Jones tend to outperform fixed rent investments, while, with the EUROSTOXX this is not the case, highlighting that not any combination of shares will yield positive results, cf. Illustration c), f), and i):

¹ With the added benefit that periodically repeated investments into the same assets will provide a natural hedge against price fluctuation. This paper, however, will not address periodical re-investment and rebalancing decisions.



Illustration a: 5-year performance of the DAX Performance Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com.



Illustration b: 5-year performance of the Dow Jones Industrial Average Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com.



Illustration c: 5-year performance of the EuroSTOXX Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com



Illustration d: 10-year performance of the DAX Performance Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com



Illustration e: 10-year performance of the Dow Jones Industrial Average Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com



Illustration f: 10-year performance of the EuroSTOXX Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com



Illustration g: 20-year performance of the DAX Performance Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com.



Illustration h: 20-year performance of the Dow Jones Industrial Average Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com



Illustration i: 20-year performance of the EuroSTOXX Index mapped against 3% and 5% fixed rate investments. Source: comdirect.com

Fig.1: Comparison of indices vs fixed income investments.

While stocks as an asset class are an attractive investment alternative for private investors, the decision-making process involved in finding the appropriate stocks to invest in and building a portfolio out of such stocks is difficult for non-expert investors, in particular given the quantity of data and information available, which while useful, can be overwhelming (Sevastjanov & Dymova, 2009).

The first difficulty arises from the many different approaches to portfolio selection and monitoring that exist. Some of these are highly sophisticated and require the decision maker to form an opinion on his or her expectations for the future, e.g. in the Black-Litterman Model (Kim, Kim, & Fabozzi, 2016). The average private investor is generally not likely to have the time, nor the knowledge, to develop a sufficiently deep understanding of the topics required in order to be able to make a well-informed decision, using the approaches currently existing. Professional analyst reports, which could provide such predictions, are not publicly available.

Another element that adds complexity to this type of decision is that every investor has different goals and preferences regarding portfolio selection (Ehrgott, Klamroth, & Schwehm, 2004; Sevastjanov & Dymova, 2009). For example, some may have a minimum required return, others may like to include their risk aversion, holding period, whether profits from the investment realize predominantly as (cash) dividends or as accumulated capital gains through the market price of the stocks²,

² This is a mostly tax-driven decision on a case-by-case basis, as E. Mondello explains in Section 1.5.2.1 - *Renditeziele* (Mondello, 2015).

or even some others may want to consider non-financial factors, such as adherence to principles of corporate governance³, or even ethical considerations.

This thesis develops a mathematical approach that combines multi-criteria decision analysis (MCDA) with integer linear programming (MCDA-ILP) to help non-sophisticated investors define a portfolio of listed stocks. The model developed is applied to the DAX-30 index as a proxy for the German stock market, and its results are compared against the classical portfolio theory approach of risk/return optimization. Both models are compared and benchmarked against the DAX as market index.⁴

The paper is organised as follows. First, the German stock market is described in section 2. Section 3 reviews some well-known theories and methods used in portfolio selection: the modern portfolio theory based on the Markowitz model, general optimization methods, and MCDA. A brief analysis of the strengths and weaknesses of each approach is presented, and conclusions are drawn in order to inform the development of our own portfolio selection approach. Thereafter follows a description of the variables deemed relevant for the decision making. Section 4

³ In particular, foreign investors, i.e. investors from a different jurisdiction than the issuer of the stock, are not necessarily familiar with the details of the rights and obligations conferred by the holding of shares. It can therefore be especially important for them to know that the company they invest in adheres to the fullest extent with what the legislator deems the best practice in Corporate Governance.

⁴ The purpose of this work is, however, academic. The model presented in it is a theoretical exercise and may require modifications to be functional for actual investment decisions. In addition, it does not address periodical portfolio evaluation and rebalancing methods. Neither this work, nor the model presented in it, are to be construed as a recommendation to buy or sell specific stocks, nor should it be relied on by any investor for making investment decisions without prior consultation of expert advice. Any person who applies the model described herein does so entirely at their own risk.

will then show the specific formulation of the MCDA-ILP model developed, and section 5 will show the results of the application and provide a brief discussion thereof.

2 The German Stock Markets

2.1 German Stock Exchanges

Germany, as a result of its being a federal state, has several regional stock exchanges across its different *Bundesländer* apart from the most well-known Deutsche Börse in Frankfurt⁵. Deutsche Börse operates the XETRA online trading platform for stocks and derivatives, where according to Deutsche Börse (“Gruppe Deutsche Börse - Handel,” n.d.), 80% of the trades in stocks on all the German stock exchanges take place.

2.2 Market Regulation and Segments

Regarding the markets for stocks, one can distinguish between the so-called regulated markets, operated by the stock exchanges and subject to the full extent of European and German legal regulation, and other trading facilities (OTC markets of the stock exchanges, or MTFs such as Chi-X, for example) on the other hand. Only the regulated markets have until now provided for an obligation to disclose all information necessary for the analyses this paper will undertake; the focus will therefore lie on stocks listed on regulated markets.

⁵ There are to this day stock exchanges in Berlin, Düsseldorf, Hamburg, Hannover, Munich, and Stuttgart (the exchange in Leipzig having specialized on energy trading, and being correspondingly designated as the European Energy Exchange, or EEX, and the European Exchange or Eurex based in Eschborn near Frankfurt specializing in derivatives)

The regulated markets are governed by the German Stock Exchange Act (*Börsengesetz*), the German Securities Trading Act (*Wertpapierhandelsgesetz*) as well as European regulations and directives. These provide for a uniform standard of organization, transparency and due conduct on behalf of the stock exchanges and the issuers of the listed securities as well as other market participants⁶. Beyond these requirements, the individual stock exchanges may create additional market segments of their regulated market⁷ where issuers submit to additional (disclosure) obligations, increasing transparency and investor-friendliness.

From among the securities listed in the Prime Standard segment of its regulated market, the Frankfurt Stock Exchange selects 30 companies⁸, in order to allow tracking what are considered “blue chips” listed in the Prime Standard.

2.3 Market Efficiency

Given the stringent transparency and reporting requirements in the Prime Standard, investors generally have immediate and equal access to all publicly available information. Hence, this market qualifies as one with semi-strong information efficiency as defined by Fama (1970). Empirical results indicate consistently that a semi-strong information efficiency of the markets prevails in developed countries (Mondello, 2015).

⁶ For example Central Counterparties, Depositaries, Clearing and Settlement Houses.

⁷ And the Frankfurt Stock Exchange has done so by creating the so-called Prime Standard.

⁸ Cf. Guide to the Equity Indices of Deutsche Börse AG, Version 7.0, December 2015, p. 19, available at http://www.dax-indices.com/EN/MediaLibrary/Document/Guide_Equity_Indices.pdf.

This means that market prices reflect all available historical and new information, and that as a consequence, no investor can consistently outperform the others based on the analysis of the available information, and for the investor, therefore, the cost and effort to procure and analyse the additional information like cash flows and expected returns do not pay off in the form of above-market returns (Mondello, 2015). This also means that the market prices are the current best estimate of the value of the issuer, including the consensus on its future perspectives, and that an investor may use these prices and their development for the analysis of the stock's performance and expected development. Therefore, an investor is unlikely to be able to consistently outperform the market based on the analysis of information publicly available, and a so-called passive management approach, aiming at replicating market performance, may be preferable to an active portfolio management (Ernst & Schurer, 2015).

The German stock markets, and in particular the stocks included in the DAX 30, are therefore well-suited for the application of the models proposed in this thesis, relying on the availability of data, and the assumption of market efficiency.

3 Approaches to portfolio selection

Portfolio selection and optimization is complex, and investment professionals have developed various approaches to assist their decision-making.

3.1 Modern Portfolio Theory

Modern portfolio theory, based on the seminal work of Harry Markowitz (Markowitz, 1952), can be traced back to his statement, “*that the investor does (or should) consider expected return a desirable thing and variance of return an undesirable thing.*”, (Markowitz, 1952). Markowitz further insists that the different assets (different shares, bonds, property, etc.) should not be considered individually or isolated from each other, but as a complete portfolio, in order to realize the advantages of diversification (Markowitz, 1952)⁹.

In other words, an investor should balance the expected returns (derived from historical returns) against risk (derived from the historical volatility) and co-variance of the returns.

The expected return of a portfolio can be calculated as the weighted sum of the expected returns of the assets comprising the portfolio,

$$\mu_p = \sum_{i=1}^n w_i \mu_i$$

(Eq. 1)

⁹ Although these thoughts are not new, the first idea of basic insurance and portfolio thinking already existed in antiquity, especially in Phoenicia, Greece, Rome and Asia Minor, where merchants joined together in a community to replace lost goods, spreading risk, (Romeike, 2005).

where μ_p is the overall expected portfolio return, n stands for the number of assets considered, w_i indicates the weight of asset i in the portfolio, and μ_i its expected return.

Portfolio risk is expressed as portfolio variance, in the basic approach, and can be calculated based on the variance of the individual assets and the correlation between them.

$$\sigma_p = \sqrt{\sum_{i=1}^N w_i^2 \sigma_i^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^N w_i w_j \text{cov}_{i,j}}$$

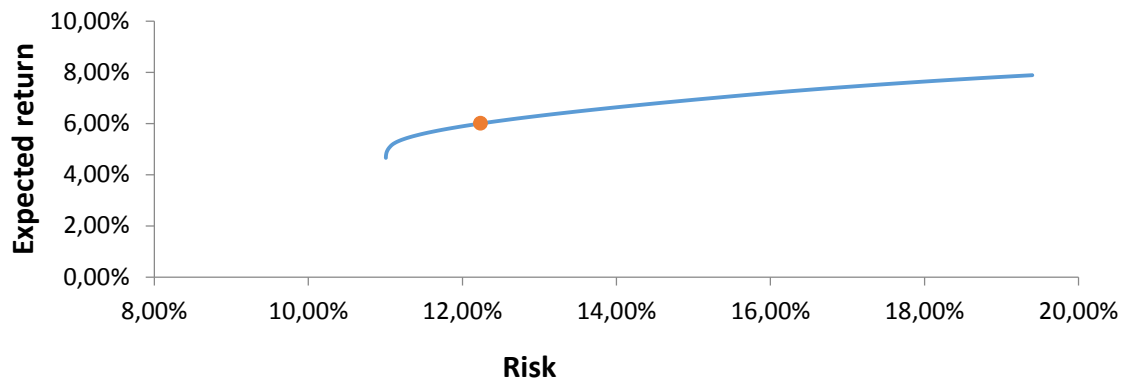
(Eq. 2)

Where σ_p is the portfolio risk, w_i is the percentage weight of asset i in the portfolio, σ_i^2 is the standard deviation of the returns of asset i , w_j is the percentage weight of asset j in the portfolio and $\text{cov}_{i,j}$ is the covariance between the return of assets i and j .

Applying these formulas to a two-asset portfolio for different weights factors and graphing the results will result in a curve similar to the one shown below¹⁰:

¹⁰ The values are merely for illustrative purposes.

Efficiency Curve



The upper frontier is called “efficient frontier curve”. Any portfolio above the curve shows characteristics which are not attainable, i.e. no combination of the two assets can yield that risk – performance combination, while any portfolio below the curve is inefficient. The curve describes the efficient risk – performance combinations based on expected returns vs. variance. So starting at the minimum variance point, higher return on investment is only possible with greater risk, and it depends on the investor which level of risk he or she is willing to accept. Hence, to determine which portfolio is “optimal” is dependent on the personal appetite for risk and the return expectation of the investor (Ernst & Schurer, 2015). Modern portfolio theory is not based on the fundamental analysis of the financial data of the individual enterprises, but on a technical analysis of the historic stock prices, since it is based on the assumption of an efficient market.

The correlation between the assets included in a portfolio defines if a portfolio is an efficient one or an inefficient one. Correlation can take values between -1 and +1,

where a correlation of +1 (positive) shows an identical behavior of assets to market changes and a correlation of -1 describes a complete opposite behavior of two assets to market changes.

From a risk perspective, it is not desirable or efficient that all assets in a portfolio show the same behavior when one incident affects the market change (correlation +1). On the other hand, from a return perspective, it is also not desirable that the correlation is -1 (complete opposite behavior to one market incident), because any positive effect on one asset would be completely canceled out by the opposite effect on the other. The goal of an efficient portfolio selection and risk management is to mitigate the value fluctuations of individual assets by risk diversification. To reach this goal, the different assets should not have the same behavior nor opposite behavior, but an independent value development (correlation 0).

3.1.1 Limitations of modern portfolio theory

Fundamental criticism of modern portfolio theory can be divided into two main points:

- a) Unusual market environments are a real challenge to any portfolio theory. For example, massive amounts of cash made available by central banks at extremely low (including negative) interest rates make it very difficult to discover investment possibilities. Normally the economy is rational, when interest rates climb, stock exchange markets loose, as investments is shifted from equity to debt, and of course, vice versa. If

government stimulates housing, money goes into construction and shifts away from other types of investment. But the enormous amount of money in the market (80 billion of bond purchase by the European Central bank per month, negative interest rate of -0,4% for overnight money at EZB, interest rate of 0% for EZB money – decision dated 10.03.2016) need to be invested somehow, therefore the correlation between the amount of money and the possibilities of production of the real economy, is practically none (Gatermann, 2010).

- b) Based on the evolution of the stock exchange values since the 50's, there are indications that the riskiest shares delivered the lowest return, and the less risky the highest. This insight is the complete opposite to the prediction of modern portfolio theory, which states that the riskiest shares should have the highest return (Gatermann, 2010).

On the other hand, the modern portfolio theory is also based on the assumption that the stock exchange market is highly efficient and that every change or new information available is reflected immediately in stock price. However, Haugen states that no market is efficient and it is possible to find undervalued shares at any time, and that markets deal with themselves and not with reality (Hiller von Gärtringen, 2016).

3.1.2 Technical criticism

Apart from the fundamental criticism levied against the modern portfolio theory, various criticisms on a more technical level have been directed at it, chiefly regarding the adequacy and robustness of the indicators used to determine return and risk¹¹, and several different ways were developed to refine the original approach (Derigs & Nickel, 2003; Ehgott et al., 2004; Kim et al., 2016; Lee, Tzeng, Guan, Chien, & Huang, 2009; Xidonas, Askounis, & Psarras, 2009; Xidonas, Mavrotas, & Psarras, 2009; Zhao, Lu, Han, Liu, & Hu, 2015).

One specific criticism against the classical approach is the number of calculations needed to obtain the required inputs: Expected returns must be calculated for every asset under consideration, and based on the calculated historical variances, the variance-covariance matrix must be established. However, while this was a justified concern when the theory was first established in the fifties, the increase in computational power of personal computers now makes this point far less relevant, in particular if, as in the present case, the number of assets under consideration is rather small (Mondello, 2015).

Another criticism related to the previous point is that, since all the aforementioned inputs are derived from historical data, there is considerable potential for estimation errors. In addition to this, the classical portfolio selection model is very sensitive to estimation errors, and therefore the results of the classical selection method may not be very reliable (Mondello, 2015,).

¹¹ Cf. Kim et al., 2016.

3.2 Other Selection Models

In order to address the main criticisms directed at the classical model, a number of alternative approaches have been developed.

One approach is to use so-called one factor models, mainly in order to reduce the number of computations needed to obtain the covariance between stocks, and thus to reduce the potential of estimation errors (Mondello, 2015). The most common of these models is the Capital Asset Pricing Model (“**CAPM**”), which describes the expected return of any stock as a function of the risk-free interest rate and the market interest rate multiplied by the asset-specific beta-factor; the latter represents the sensitivity of the asset’s return to changes in the market’s return (Mondello, 2015). In other words, the beta factor expresses the company-specific risk in relation to the average risk in the market.

The CAPM assumes perfectly efficient markets, in which all investors have identical expectations regarding the future development. Therefore, all investors should calculate the same intrinsic value for any given asset, and, by buying undervalued assets and selling overvalued assets, would cause the market price to conform to the intrinsic value, which is why it is also called an equilibrium model (Mondello, 2015).

Other approaches, such as the Black-Litterman model (Kim et al., 2016), or the Treynor/Black model (Mondello, 2015), combine a passive/market portfolio based element, where the investor relies on the CAPM to determine a generally reliable

equilibrium value for those assets on which s/he cannot form more precise expectations for the future, and an active portfolio element, comprised of assets which the investor identifies as undervalued based on his or her specific industry knowledge or expectations. Since the model to be developed in this work is intended for use by unsophisticated investors, these models can be disregarded, since they would require the investor to form specific expectations on one or several of the prospective assets. Absent such specific expectations, application of these models would simply yield the same results as CAPM (Mondello, 2015).

Finally, to address the inherent problems with the sensitivity of the inputs (i.e. expected return and risk) to estimation error, so-called robust portfolio selection approaches have been developed. These focus mainly on two areas: reducing the estimation error as such by proposing the use of other indicators for expected return and risk which are less prone to estimation error, and reducing the effects of estimation errors on the result by modifying the optimisation model itself (Ernst & Schurer, 2015).

3.3 MCDA and Optimization

MCDA is a decision aid approach that aims at balancing several criteria at the same time, based on objectified measurements of obtainable value and utility (Belton & Stewart, 2002). Its principal strength is that it breaks down complex situations with potentially contradicting aims into several relatively simple, accessible elements, rating them and showing how each factor contributes to the

overall evaluation of each proposed solution (Henao & Benavides, 2012). At the same time, MCDA results in a single indicator that collapses the multiple perspectives offered by the individual criteria into a single indicator (Phillips & Bana E Costa, 2007).

The output of MCDA-based evaluation can be used as input for optimization operations (Montibeller, Franco, Lord, & Iglesias, 2009), which will strive to maximize the benefit, attributed by the MCDA to different alternatives, subject to certain constraints determined by the decision maker, and relative to a cost or risk indicator. This gives the decision maker a more granular view on how each option scores in the aggregate, but also with respect to individual performance criteria, which are weighted in accordance with their importance to the decision maker (Henao & Benavides, 2012). A linear programming approach can be used to maximize the benefit¹² the investor would realize through the portfolio (Phillips & Bana E Costa, 2007), based on the valuation of the stocks through MCDA.

Seen in this light, the Markowitz portfolio selection approach is itself a two-factor optimization (minimize risk for given return, or vice-versa), subject to, for example, complete utilization of funds, certain maximum weights per asset, maximum number of assets, prohibition of short-selling¹³.

¹² As defined below.

¹³ Short-selling occurs when an investor agrees to sell and transfer, at a future point in time, shares which s/he does not, at the time of sale, hold. Short sales are potentially attractive for the seller when the seller assumes to face falling prices of the asset; then, prior to settlement, the seller will be able to procure the assets to be transferred at a lower cost than the agreed upon sales price, thus realizing a profit. If, on the other hand, prices were to rise above the agreed sales price, the

However, in its optimizing functionality, it is only concerned with balancing the expected return with the risk. Empirical findings do suggest that in reality, investors tend to select portfolios which are below the efficient frontier according to the “pure” classical approach (Konno, 1990), i.e. which are dominated portfolios when only evaluating the expected return and risk. A possible explanation may be that return and risk, which are the only variables taken into account in classical portfolio theory, do not reflect all aspects important to real-life investors (Ehrgott et al., 2004). Xidonas, Mavrotas, et al., 2009, repeatedly point out the classical model’s inability to take investor-specific preferences into account, and conclude that *the use of the classical approach seems to be necessary but not sufficient, to manage portfolio selection efficiently*. In other words, even though a portfolio may be dominated when evaluated only under the perspective of risk and return, but may make up for this in other criteria not considered by the classical approach, making it not dominated in a multicriteria setting (Ehrgott et al., 2004).

4 The MCDA – ILP Model

The model developed in this thesis is based on a combination of MCDA and Integer Linear Programming (“**ILP**”).

As discussed earlier (cf. 3.3), the decision-making process for portfolio selection may need to consider additional criteria (beyond variation as risk measure and expected return based on historical average), in order to better represent the

seller would have to procure the assets at a loss; hence, short positions, while potentially creating an unlimited upside potential, also entail a significant loss risk.

preferences and profile of the investor or decision maker. Such criteria could be either more granular descriptors of return and risk, or new aspects that the individual investor perceives as relevant for his or her specific situation (Ehrgott et al., 2004).

The question is which decision criteria to use. One could think of further breaking down the two fundamental criteria of risk and expected return, e.g. into short- and long-term performance, volatility and credit rating (Ehrgott et al., 2004), or introduce elements from fundamental analysis to reflect an investor's preferences for certain business practices, or reflecting individual investor goals (Xidonas, Mavrotas, et al., 2009).

While a premise of this thesis is that the market in which the stocks to be evaluated are listed is a (semi-strong) efficient market, and that therefore fundamental analysis should not yield above-market returns, there are certain indicators derived from fundamental analysis which may hint at a company being more or less well positioned to confront future challenges, to be more or less likely to face liquidity problems, or being more or less conservatively valued by the market (Mondello, 2015). These may therefore be viewed as factors ultimately affecting the risk of an investment in said stocks, in line with the Value Investment approach (Ernst & Schurer, 2015)¹⁴.

¹⁴ Taking the life cycle phase of the enterprises comprising the DAX into account, a value investment approach is adequate, given that all or at least the majority of the enterprises are mature, cf. also Ernst & Schurer, 2015, p. 48 et seq.

4.1 MCDA criteria

The model proposed in this thesis is based on the assumption that the investor qualifies as defensive¹⁵. Graham (Graham & Zweig, 2003) suggests several criteria for this investor type to decide whether or not to invest in a stock. Some of these criteria will be used, slightly modified, to evaluate the stocks in the MCDA framework. Generally, the focus lies on indicators connected to the income generation and yield potential of a company, as well as on the capacity to finance its business without taking out (excessive) debt. The weights attributed to the individual criteria under this model are not fixed, but need to be adapted to reflect the individual needs of each investor. Also, investors may include additional criteria.

The criteria used for the model are:

4.1.1 Price/Earnings ratio:

The PER is, in a way, an indicator for the time it would take until the purchase price is amortized by the earnings. Viewed from a different perspective, it indicates that the market is willing to pay less for the company's potential to generate income than it is in other companies. This may be due to the perception that the company is a riskier investment than others, or that the market does not appreciate fully the potential of the company, resulting in a temporary undervaluation, and that thus an

¹⁵ A defensive investor is someone who wants safety and freedom from bother. He has no time to analyze and watch stock exchange markets and/or companies. He expects a return of investment in dividend rate similar to general interest rate, and an appreciation of his investment according to the major market indices (Graham & Zweig, 2003).

increase in the stock price can be expected, assuming the correction by an efficient market. Under this perspective, lower values will be better.

PER is calculated as follows:

$$PER = \frac{\text{Market value per share}}{\text{Earnings per share}}$$

(Eq. 3)

This criterion will receive a weight of 25%. The weight of this criterion is set relatively high because it indicates a potential valuation anomaly in the market.

4.1.2 Dividend Growth

This criterion shows the average growth of dividends¹⁶ paid over the past 3 years. This factor indicates whether the company tends to distribute more to its investors, and indirectly¹⁷ whether a company is increasing its profitability. Higher growth rates are better.

Average dividend growth is calculated as follows:

¹⁶ **Dividend:** The dividend is the distribution of profits of a corporation. The distribution amount is not equal to the net income as part of the profit can be destination of different kind to reserves (for future investments, legal issues, etc.). The amount of dividend per share is decided by the General Assembly of shareholders after a recommendation of the corporation's management. While in England and the United States, the dividend is paid normally on a quarterly basis, in Germany it is paid regularly annually. It is also possible that in some cases the shareholder can decide if he wants the dividend in money, or in shares of the company (Optional dividend in money or shares).

¹⁷ The relationship between profitability and dividend growth is indirect, because the dividend distribution is a result of the decision on the use of utilities; it may be that a company increases its utilities, but decides to distribute less dividends.

$$\text{Div. growth average} = \frac{\text{Dividend growth 2012} + \text{Dividend growth 2013} + \text{Dividend growth 2014}}{3}$$

(Eq. 4)

This criterion will receive a weight of 15%, assuming an investor who wants to receive a higher portion of cash in the future.

4.1.3 Earnings per Share growth

This criterion indicates the average growth of Earnings per Share¹⁸ over the last 3 years. EpS growth, indicates the development of the ability of the company to generate utilities, regardless of whether these are distributed or retained. Higher growth rates are better. Earnings per share are calculated on the part of the generated annual and consolidated net income attributable to one share. It measures the profitability in relation to the number of shares. Especially in America this variable is in the center of attention, as it is specified for measurable targets. The standardized DVFA (*Deutsche Vereinigung für Finanzanalyse und Asset Management* – German association for financial analysis and asset management) earnings method is taken as a basis for reporting of the profit per share in Germany.

Earnings per share are calculated as follows:

$$EpS = \frac{\text{Net income} - \text{Dividends on preferred stock}}{\text{average outstanding shares}}$$

(Eq. 5)

Average growth of EpS is calculated as follows:

$$EpS \text{ growth average} = \frac{EpS \text{ growth 2012} + EpS \text{ 2013} + EpS \text{ 2014}}{3}$$

(Eq. 6)

This criterion will receive a weight of 15%, because it indicates the ability of a company to increase the profitability for its shareholders, regardless of whether the profits are distributed as dividend.

4.1.4 Short Term Financial Condition

Current assets should be at least twice current liabilities. The short term financial condition, calculated as the ratio of current assets to current liabilities, indicates the extent to which the company is dependent on debt for its day-to-day operation, or differently said, whether it could, if necessary, repay its short-term liabilities using readily available current assets. Higher values are better.

The short term financial condition is calculated as follows:

$$\text{Financial condition 1} = \frac{\text{Current assets}}{\text{Current liabilities}}$$

(Eq. 7)

This criterion will receive a weight of 15%.

4.1.5 Long Term Financial Condition

Long term debt should not exceed the net current assets (“working capital”). The long term financial condition, calculated as the ratio of long term debt to current assets, indicates to what extent the company is financed through long term debt. It favours companies that rely on internal funding. Lower values are better.

The long term financial condition is calculated as follows:

$$\text{Financial condition 2} = \frac{\text{Long term debt}}{\text{Current assets}}$$

(Eq. 8)

This criterion will receive a weight of 10%. Together with the short term financial condition, this factor therefore weighs 25%, allowing a substantial weight to indicators based on the company’s financial health and not only results.

4.1.6 Return on Equity

In addition to the criteria developed by Graham, the average Return on Equity over the past three years will be used. Return on Equity, calculated as the amount of net income shown as a percentage of shareholders’ equity indicates a company’s profitability, i.e. its capacity to generate income with the equity invested. This indicator balances the preference for low debt levels introduced by the long term financial condition indicator, given that return on equity benefits from debt financing. Return on equity is calculated by dividing the net income (pre-tax profit

and before dividends for common stock, but after dividends for preferred stock) by the shareholder's equity. The lower the shareholders' equity, the higher the return on equity.

ROE is calculated as follows:

$$ROE = \frac{\textit{Net income}}{\textit{Shareholders equity}}$$

(Eq. 9)

This criterion will receive a weight of 10%.

4.1.7 Dividend Yield

Finally, dividend yield, calculated as the return on the price of the share through received dividend payments, will be used. This criterion permits to take into account how important it is to an investor to receive cash from his investments versus accumulating value in the development of the share prices.

Dividend yield is calculated as follows:

$$\textit{Dividend yield} = \frac{\textit{Dividend paid}}{\textit{Share price}}$$

(Eq. 10)

This criterion will receive a weight of 10%.

4.2 MCDA calculation and result

In each case, the absolute values for each stock with respect to each criterion have been compiled and then normalized on a scale from 0 to 100 to allow for easier comparison.

To do so, regarding criteria where higher values are regarded as better (e.g. growth indicators), the highest absolute value is set as a value of 100, the lowest to zero, and the remaining values are converted proportionately. For criteria where lower values are considered better (e.g. the PER), the same approach in reverse has been applied. Then, the scores obtained in each criterion have been multiplied with the weight assigned to each criterion, and the total score (or total benefit) for each share has been obtained by adding the weighted scores.

Where higher scores are better, the following formula has been used for normalization:

$$\frac{x - x_{min}}{x_{max} - x_{min}} * 100$$

(Eq. 11)

where x is the value to be normalized, x_{max} is the greatest value obtained by any stock for that criterion, and x_{min} is the lowest value obtained by any stock for that criterion.

Conversely, where lower scores are better, the formula used is:

$$\frac{x_{max} - x}{x_{max} - x_{min}} * 100$$

(Eq. 12)

where x is the value to be normalized, x_{max} is the greatest value obtained by any stock for that criterion, and x_{min} is the lowest value obtained by any stock for that criterion.

The formula to calculate the overall score or rating V_i for each stock i is as follows:

$$V_i = \sum_{c=1}^7 w_c V_{c,i}$$

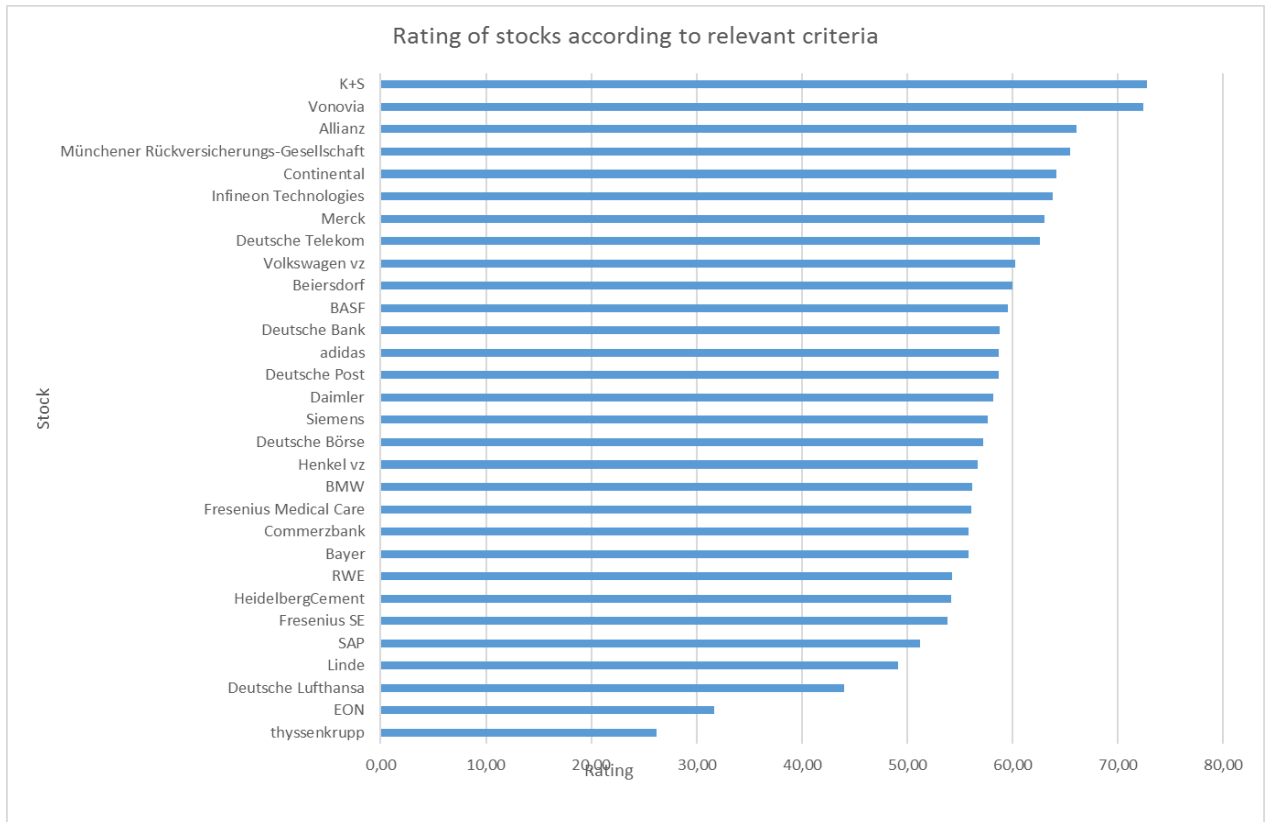
(Eq. 13)

Where w_c is the weight assigned to the criterion and $V_{c,i}$ is the normalized score of stock i regarding the relevant criterion.

The result can be seen in the following table and graph:

STOCK	PER	Dividend growth	EpS growth	Financial Condition 1	Financial Condition 2	ROE	Dividend yield	Rating
adidas	97,87	41,33	13,20	33,36	93,66	81,73	35,22	58,7103 0
Allianz	99,61	41,71	43,27	13,01	98,96	81,76	83,80	66,0528 3
BASF	98,99	26,79	10,08	35,05	79,28	90,88	69,93	59,5463 4
Bayer	95,36	35,74	22,60	24,56	67,21	86,02	42,06	55,8017 8
Beiersdorf	95,26	21,93	37,21	47,87	96,60	85,33	19,59	60,0177 0
BMW	99,57	32,13	17,99	7,58	78,62	86,65	60,95	56,1685 6
Commerzbank	90,34	21,93	75,42	11,29	100,00	69,58	0,00	55,8398 5

Continental	98,66	60,27	32,41	20,53	85,95	93,21	45,83	64,1440 6
Daimler	99,46	26,63	18,91	14,41	78,90	86,09	78,15	58,1728 6
Deutsche Bank	97,49	21,93	48,88	16,15	95,91	70,72	46,70	58,7492 6
Deutsche Börse	98,55	18,27	12,62	9,02	99,95	93,14	72,63	57,1969 5
Deutsche Lufthansa	73,73	64,01	0,00	0,00	60,23	81,24	18,20	44,0022 7
Deutsche Post	98,18	30,57	30,12	10,22	79,58	90,28	64,66	58,6340 7
Deutsche Telekom	97,05	9,91	88,44	10,99	52,10	67,28	100,00	62,6015 9
EON	0,00	0,00	37,05	16,06	68,70	69,05	99,18	31,6596 9
Fresenius SE	96,68	38,71	22,60	23,80	65,07	82,69	21,34	53,8467 3
Fresenius Medical Care	97,67	27,26	13,39	42,50	65,22	100,0 0	26,37	56,0466 9
HeidelbergCement	96,49	58,51	37,05	3,33	56,78	73,72	21,34	54,1402 2
Henkel vz	96,20	44,88	20,54	16,77	88,97	86,16	27,87	56,6803 6
Infineon Technologies	98,13	42,97	12,14	61,29	97,07	80,95	40,18	63,8124 5
K+S	99,14	100,00	2,00	74,37	74,65	84,28	56,50	72,7834 8
Linde	95,68	32,07	10,57	6,28	60,63	79,98	37,66	49,0860 7
Merck	94,82	34,70	38,52	57,63	90,20	78,81	27,87	63,0199 9
Münchener Rück	99,83	31,38	100,00	0,16	34,88	82,54	90,14	65,4457 1
RWE	99,78	0,89	29,09	13,88	69,58	68,82	88,51	54,2161 2
SAP	96,86	24,00	13,31	10,73	75,66	91,70	30,70	51,2252 3
Siemens	98,43	26,14	13,15	20,24	92,10	86,55	62,15	57,6139 7
thyssenkrupp	0,00	64,01	37,88	14,04	84,59	0,00	3,08	26,1554 6
Volkswagen vz	100,0 0	43,01	13,11	33,57	87,99	87,77	42,00	60,2276 0
Vonovia	97,86	68,81	70,55	100,00	0,00	78,65	41,81	72,4156 6
	MIN	MAX	MAX	MAX	MIN	MAX	MAX	
Weight	25%	15%	15%	15%	10%	10%	10%	



4.3 ILP optimization

4.3.1 Primary equation of the proposed model

The primary equation of the MCDA-ILP model is intended to maximize the total benefit received by investing in the portfolio. In this context, the rating obtained based on the weighted normalized scores has to be put in relation to the price of acquiring a position in these stocks.

$$MAX \sum_{i=1}^n \frac{V_i}{P_i} x_i$$

(Eq. 14)

Where V_i is the rating of the stock obtained through application of the MCDA part, P_i is the price of the stock i , n is the total number of stocks included in the portfolio and x_i the number of shares of the stock i .

4.3.2 Constraints

In addition to the criteria mentioned above, certain constraints are introduced with which the portfolio must comply:

4.3.2.1 *No short sales*

$$x_i \geq 0$$

(Eq. 15)

where x_i is the number of shares of stock i . This constraint serves to eliminate short sales.

4.3.2.2 *Number of shares integer*

$$x_i \in \mathbb{Z}$$

(Eq. 16)

where x_i is the number of shares of stock i . This constraint ensures that the number of each share to be bought is an integer, and is necessary because the German stock exchange system does not allow to buy fractions of shares.

4.3.2.3 Complete use of funds

$$\sum_{i=1}^n x_i p_i \leq B$$

(Eq. 17)

where x_i is the number of shares of the respective stock in the portfolio, p_i is the market price of the respective stock at the time of selection, n is the total number of stocks included in the portfolio, and B is the total budget allocated to investment. This constraint ensures that all the available funds will be invested. For the purpose of this exercise a Budget of EUR 150.000 will be allocated.

4.3.2.4 Target beta factor equal to one

The target beta factor of the portfolio constructed through MCDA – ILP analysis should be at most equal to 1, i.e. the investor is only willing to assume the general market risk.

$$\sum_{n=1}^n \frac{P_n x_n}{\sum_{n=1}^n P_n x_n} \beta_n \leq 1,0$$

(Eq. 18)

where P_n is the price of each stock, x_n is the number of shares of each stock to be purchased, and β_n is the three-year beta factor.

4.3.2.5 Diversification

$$P_i x_i \leq 0,2 \sum_{i=1}^n P_i x_i$$

(Eq. 19)

where P_i is the price of a share of stock i , and x_i is the number of shares of stock i to be purchased.

This restriction guarantees a minimum of diversification of the portfolio, as the total amount of each number of shares multiplied with each price cannot be greater than 20% of the total budget allocated.

4.4 Complete Formulation of MCDA-ILP model

The complete formulation for the MDA-ILP model therefore is as follows:

$$\begin{aligned} \text{Max} \quad & \sum_{i=1}^n \frac{V_i}{P_i} x_i \\ \text{s.t.} \quad & x_i \geq 0 \\ & x_i \in \mathbb{Z} \\ & \sum_{i=1}^n x_i p_i \leq B \end{aligned}$$

$$\sum_{n=1}^n \frac{P_n x_n}{\sum_{n=1}^n P_n x_n} \beta_n \leq 1,0$$

$$P_i x_i \leq 0,2 \sum_{i=1}^n P_i x_i$$

(Eq. 20)

4.5 Proposed portfolio

Applying these formulas to data compiled for the years ended December 31, 2012, 2013 and 2014, respectively, the MCDA-ILP model proposes the following portfolio:

Stock	# of shares	Price	Value	Weight
Commerzbank	2676	11,21	29.998	20,00%
Deutsche Bank	1	25,26	25	0,02%
Deutsche Lufthansa	2136	14,04	29.989	19,99%
Deutsche Telekom	2274	13,19	29.994	20,00%
EON	1	14,03	14	0,01%
Infineon Technologies	3374	8,89	29.995	20,00%
K+S	1322	22,68	29.983	19,99%
Total Portfolio			149.999	

growth 2014										
EpS growth 3 years average	12,50%	12,50%	7,14%	7,14%	50,00%	7,14%	7,14%	7,14%	7,14%	7,14%
Financial Condition 1	7,50%	12,50%	7,14%	7,14%	7,14%	50,00%	7,14%	7,14%	7,14%	7,14%
Financial Condition 2	7,50%	12,50%	7,14%	7,14%	7,14%	7,14%	50,00%	7,14%	7,14%	7,14%
Average return on equity 3 Years	10,00%	12,50%	7,14%	7,14%	7,14%	7,14%	7,14%	50,00%	7,14%	7,14%
Dividend yield	10,00%	12,50%	7,14%	7,14%	7,14%	7,14%	7,14%	7,14%	50,00%	7,14%
Expected return	12,50%	12,50%	7,14%	7,14%	7,14%	7,14%	7,14%	7,14%	7,14%	50,00%
Total	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

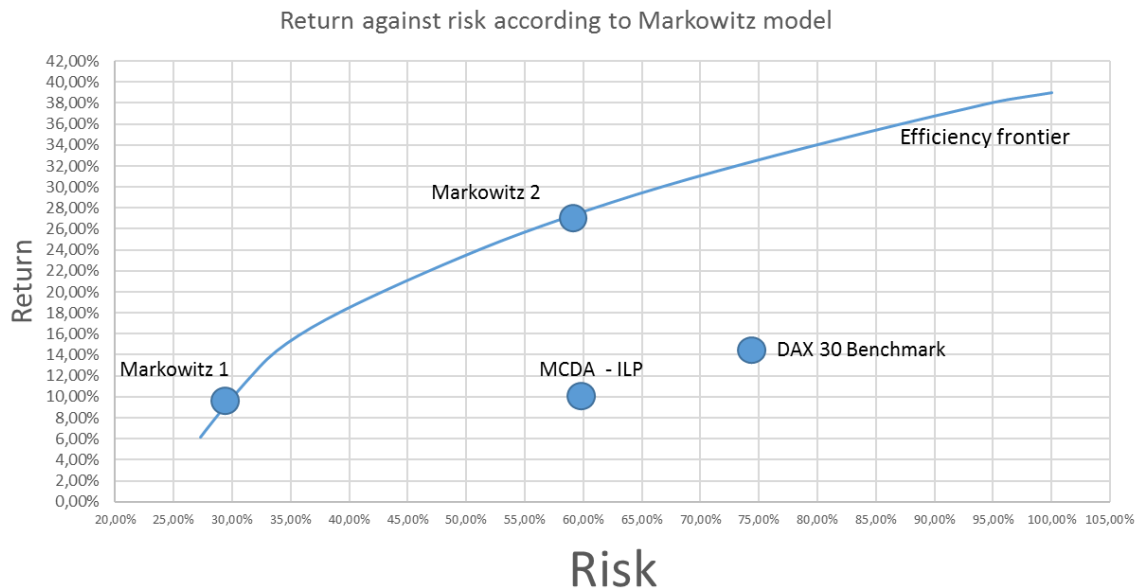
When used to select portfolios according to the proposed MCDA-ILP Model, it shows that there are three basic types of selections made, with models 1, 2, 5, 7, 8, 9, and 10 being basically identical, models 3 and 4 being almost identical, and model 6 being different from all other selections. This shows that the selection is not very sensitive to shifting criteria weights. The following table shows the results of selection by indicating the number of shares selected in each case:

Siemens	0	0	0	0	0	0	0	0	0	0
thyssenkrupp	0	0	0	1	0	0	0	0	0	0
Volkswagen vz	0	0	0	0	0	0	0	0	0	0
Vonovia	0	0	0	0	1	0	0	0	0	0

5 Comparison of proposed model vs. modern portfolio theory vs. Benchmark DAX 30 and discussion of performance

This section compares the performance of the portfolio selected based on the MCDA-ILP model with the performance of two portfolios selected by applying the classical Markowitz portfolio theory on data covering the three years 2012, 2013 and 2014.

One of the comparison portfolios (Markowitz 1) has been designed to have an expected return similar to the MCDA-ILP portfolio, while the second (Markowitz 2) has been designed to have a risk value similar to that of the MCDA-ILP portfolio. The following graph shows where each portfolio and the DAX as benchmark would fall relative to their risk/return profile:

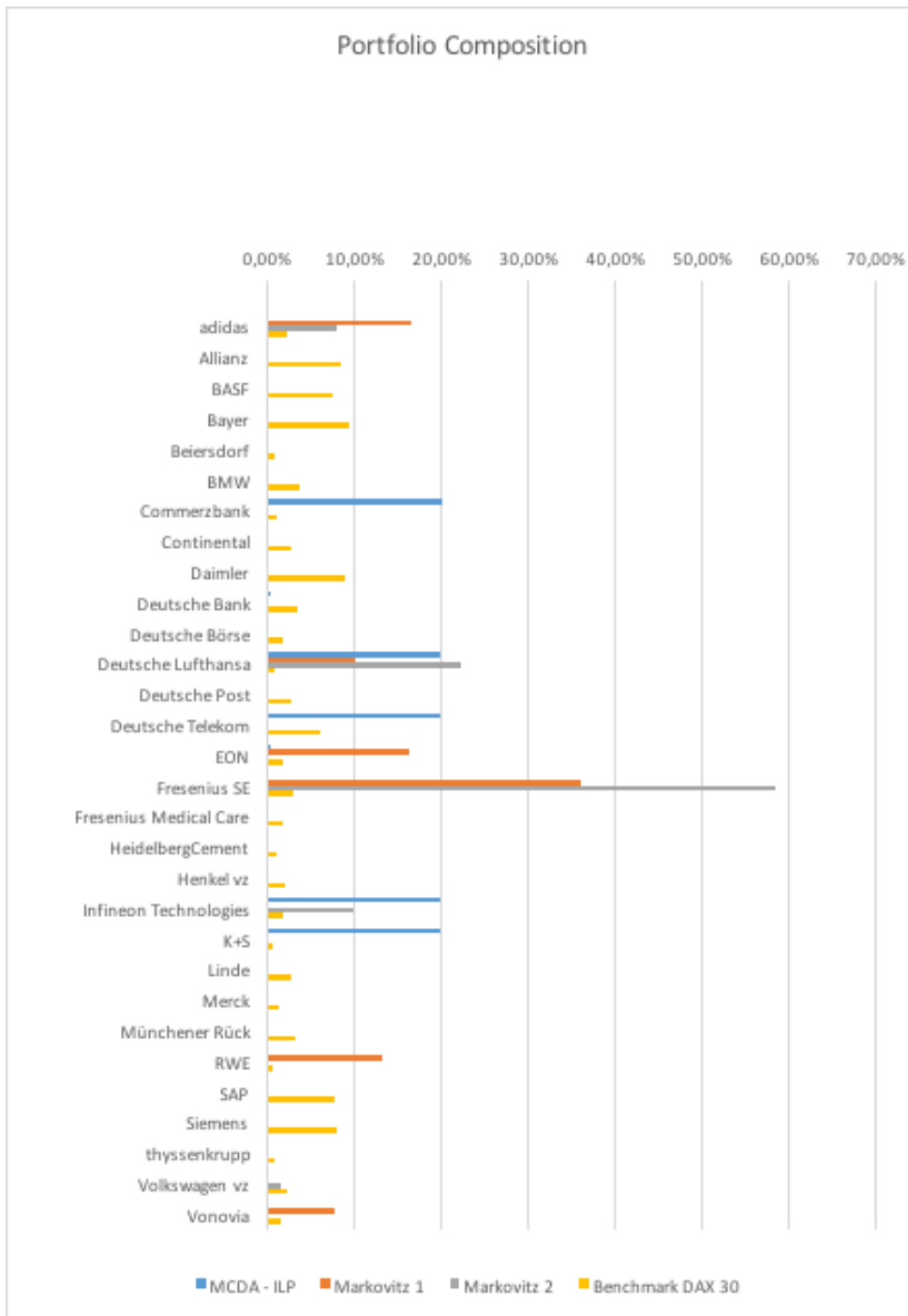


All three selection portfolios will be benchmarked against the performance of the DAX as the underlying market. In each case, a total budget of 150,000 EUR will be invested. The discussion in this chapter is based on the performance each portfolio would have realized if the shares had been bought on January 2, 2015, and sold on December 28, 2015, i.e. the first and last trading day of 2015.

The following table shows the composition of the different portfolios as they result from the MDA-ILP model and the application of modern portfolio theory:

STOCK	MCDA - ILP	Markovitz 1	Markovitz 2	Benchmark DAX 30
adidas	0.00%	16.47%	7.91%	2.15%
Allianz	0.00%	0.00%	0.00%	8.48%
BASF	0.00%	0.00%	0.00%	7.43%
Bayer	0.00%	0.00%	0.00%	9.41%
Beiersdorf	0.00%	0.00%	0.00%	0.94%
BMW	0.00%	0.00%	0.00%	3.58%
Commerzbank	20.00%	0.00%	0.00%	1.16%
Continental	0.00%	0.00%	0.00%	2.75%
Daimler	0.00%	0.00%	0.00%	8.82%
Deutsche Bank	0.02%	0.00%	0.00%	3.46%
Deutsche Börse	0.00%	0.00%	0.00%	1.69%
Deutsche Lufthansa	19.99%	10.21%	22.19%	0.75%
Deutsche Post	0.00%	0.00%	0.00%	2.84%
Deutsche Telekom	20.00%	0.00%	0.00%	6.02%
EON	0.01%	16.42%	0.00%	1.89%
Fresenius SE	0.00%	36.02%	58.42%	3.05%
Fresenius Medical Care	0.00%	0.00%	0.00%	1.87%
HeidelbergCement	0.00%	0.00%	0.00%	1.16%
Henkel vz	0.00%	0.00%	0.00%	2.05%
Infineon Technologies	20.00%	0.00%	9.88%	1.75%
K+S	19.99%	0.00%	0.00%	0.51%
Linde	0.00%	0.00%	0.00%	2.64%
Merck	0.00%	0.00%	0.00%	1.31%

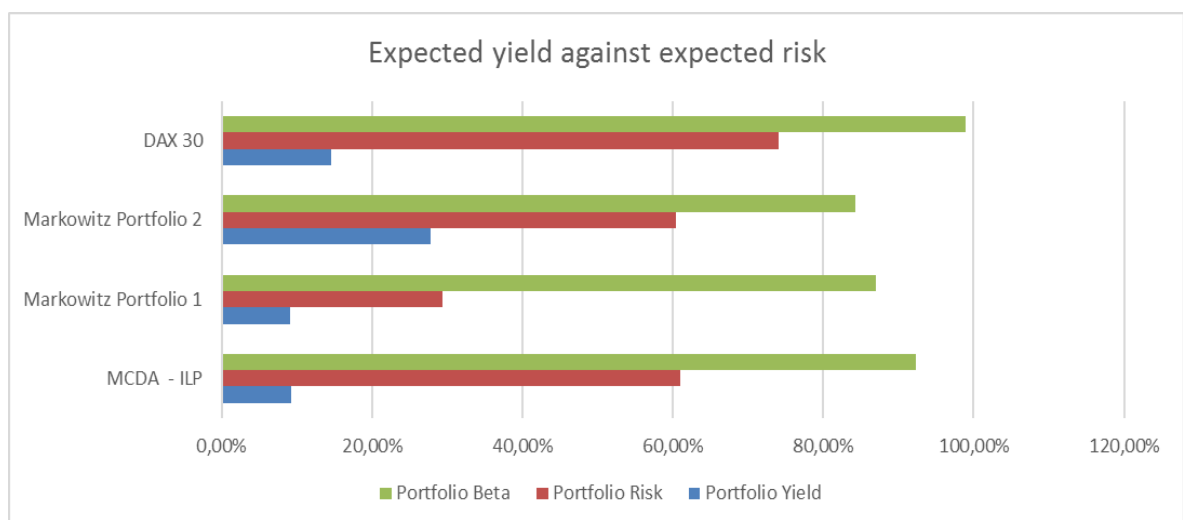
STOCK	MCDA - ILP	Markovitz 1	Markovitz 2	Benchmark DAX 30
Münchener Rückversicherungs- Gesellschaft	0.00%	0.00%	0.00%	3.15%
RWE	0.00%	13.10%	0.00%	0.62%
SAP	0.00%	0.00%	0.00%	7.79%
Siemens	0.00%	0.00%	0.00%	7.96%
thyssenkrupp	0.00%	0.00%	0.00%	0.88%
Volkswagen vz	0.00%	0.00%	1.60%	2.36%
Vonovia	0.00%	7.78%	0.00%	1.51%



The table and graph show the composition of each of the portfolios and of the DAX 30.

The following table and graph show the expected return, the portfolio risk as measured based on variance, and the portfolio beta for each of the four portfolios. In order to obtain comparable metrics, portfolio risk for the recommended portfolio (MCDA – ILP) and the DAX Benchmark portfolio are calculated based on the variance-covariance approach used in modern portfolio theory.

	Expected Yield	Portfolio Risk	Portfolio Beta
MCDA - ILP	9,20%	60,97%	0,92386
Markowitz Portfolio 1	9,17%	29,39%	0,87074
Markowitz Portfolio 2	27,81%	60,35%	0,84281
DAX 30	14,52%	74,10%	0,98989



It is interesting to note that both Markowitz portfolios, which are not subject to a risk limiting constraint, show lower risk indicators than the DAX 30, while the Markowitz 2-portfolio shows almost double the expected yield than the DAX 30. Also, while the Markowitz Portfolio 2 has a higher risk assessment based on variance, interestingly its portfolio risk as measured by the beta factor, i.e. the inherent risk of the specific companies selected, is the lowest.

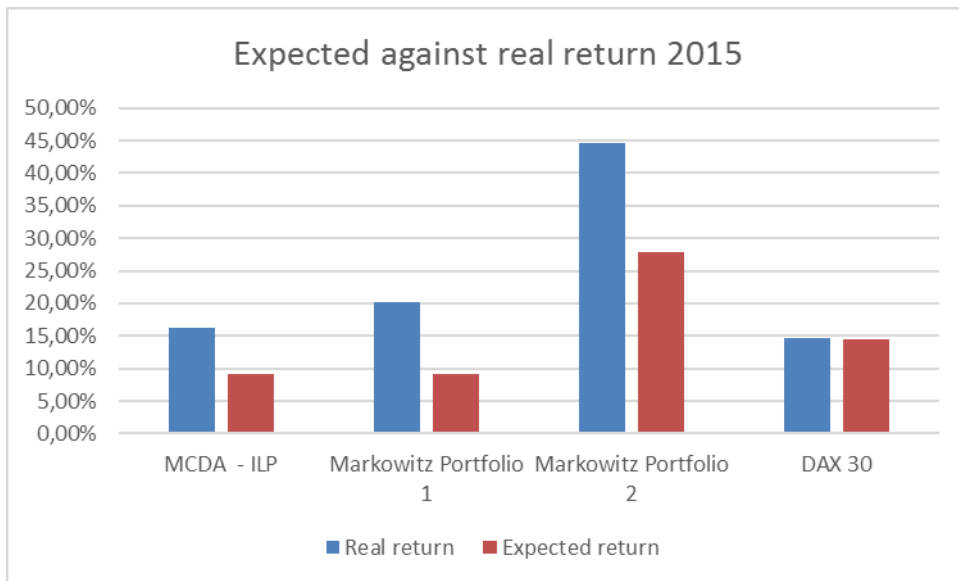
Comparing the results based on actual figures for 2015, the table shows following values:

(all values in EUR)	Investment 01.01.2015	Cash 02.01.2015	Portfolio 28.12.2015	Dividend	Final Value	Return
MCDA - ILP	149,998.57	1.43	171,501.54	2,935.37	174,438.34	16.29%
Markowitz Portfolio 1	149,997.07	2.93	176,095.27	4,225.80	180,324.00	20.22%
Markowitz Portfolio 2	149,961.57	38.43	213,564.50	3,253.24	216,856.17	44.61%
DAX 30	149,970.59	29.41	167,371.09	4,509.40	171,909.90	14.63%

The Markowitz Portfolio 2, which had the highest expected return, did perform best in real life. All three selection-based portfolios have outperformed the benchmark.

The following table and graph show a comparison of the expected and real return of each portfolio and the DAX 30.

	Real return	Expected return
MCDA - ILP	16.29%	9.20%
Markowitz Portfolio 1	20.22%	9.17%
Markowitz Portfolio 2	44.61%	27.81%
DAX 30	14.63%	14.52%



The DAX has almost perfectly met its predicted return, with an outperformance of 0.11 percentage points. All of the selection portfolios have outperformed their expected return, with both Markowitz portfolios showing the best performance.

The portfolio suggested as a result of the MCDA-ILP model would have shown, in the year 2015, a return on investment of 16.29%. It would therefore have outperformed its expected return, and beaten the DAX. It has fallen short of the performance of the Markowitz Portfolios; however, this is not surprising given that these portfolios were selected applying the modern portfolio theory with only budget and short sale prohibition as restraints, which is a model specifically designed to optimize return.

5.1 Conclusion

This thesis has shown that, combining MCDA and ILP, it is possible to build a portfolio that has a higher return than the market benchmark while at the same

time showing a lower risk. However, this portfolio has shown lower return than portfolios selected in line with the classical portfolio theory approach for a one-year period.

These limitations on performance are, however, compensated by the possibility the MCDA-ILP approach gives the decision maker to expand the model to include other criteria to better suit his or her preferences. In addition, the criteria selected for the MCDA-ILP model in this thesis were chosen in line with a value investment approach and should favour stocks that have an advantage in the long run given the focus on the fundamental analysis of indicators hinting at development potential and soundness of the firm rather than optimizing the performance measured by risk and return as defined for the modern portfolio theory. Therefore, if the selected portfolios were held for a longer period of time, the MCDA-ILP portfolio should catch up with the Markowitz Portfolios.

5.2 Limitations of the Proposed Model

The proposed model, by its design, is subject to certain limitations.

- It does not use expected return as a criterion, and therefore the resulting selection does not directly select for high return.
- It uses the beta factor as approximation for risk instead of volatility, and thus measures risk of individual shares under a different point of view than the classic portfolio theory approach

- It does select for an overall compounded benefit cost ratio, and therefore by its nature shows weaker results when plotted against the classical portfolio theory models in a return/risk matrix.
- The classical portfolio theory is a short-term model with constant changes, the proposed model although is middle- and long term oriented without changes in portfolio composition.

REFERENCES

- Belton, V., & Stewart, T. (2002). *Multiple Criteria Decision Analysis – An Integrated Approach*. Kluwer Academic Publishers.
- Derigs, U., & Nickel, N.-H. (2003). Meta-heuristic based decision support for portfolio optimization with a case study on tracking error minimization in passive portfolio management. *OR Spectrum*, (25), 345–378.
- Ehrgott, M., Klamroth, K., & Schwehm, C. (2004). An MCDM approach to portfolio optimization. *European Journal of Operational Research*, 155(3), 752–770.
- Ernst, D., & Schurer, M. (2015). *Portfoliomanagement - Theorie und Praxis mit Excel und Matlab* (utb). Konstanz: UVK Verlagsgesellschaft mbH.
- Fama, E. F. (1970). Efficient Capital Markets - A Review of Theory and Empirical Work. *The Journal of Finance*.
- Gatermann, M. (2010). Risikomanagement: Ist Markowitz' Portfoliotheorie überholt? - manager magazin. *Manager Magazin*. Retrieved from <http://www.manager-magazin.de/finanzen/alternativegeldanlage/a-728830.html>
- Graham, B., & Zweig, J. (2003). *The Intelligent Investor* (Revised Ed). New York: HarperBusiness Essentials.
- Gruppe Deutsche Börse - Handel. (n.d.). Retrieved February 2, 2016, from http://deutsche-boerse.com/dbg/dispatch/de/kir/dbg_nav/investor_relations/10_The_Company/30_Business_Areas/30_Trading
- Henao, F., & Benavides, J. (2012). Una Aproximación Multimetodológica para la Definición de Portafolios de Proyectos de Inversión. *Academia, Revista Latinoamericana de Administración*, (50), 79–99.
- Hiller von Gärtringen, C. (2016). Portfoliostrategie: Risiko wird zur entscheidenden

Stellgröße - Strategie & Trends - FAZ. Retrieved March 13, 2016, from <http://www.faz.net/aktuell/finanzen/strategie-trends/portfoliostrategie-risiko-wird-zur-entscheidenden-stellgroesse-128635.html>

- Kim, W. C., Kim, J. H., & Fabozzi, F. J. (2016). *Robust Equity Portfolio Management + Website: Formulations, Implementations and Properties Using MATLAB*. Hoboken: John Wiley & Sons.
- Konno, H. (1990). Piecewise linear risk function and portfolio optimization. *Journal of the Operational Research Society of Japan*, 33(2), 139–156.
- Lee, W. S., Tzeng, G. H., Guan, J. L., Chien, K. T., & Huang, J. M. (2009). Combined MCDM techniques for exploring stock selection based on Gordon model. *Expert Systems with Applications*, 36(3 PART 2), 6421–6430.
- Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, 7(1), 77–91.
- Mondello, E. (2015). *Portfoliomanagement* (2nd ed.). Wiesbaden: Springer Fachmedien Wiesbaden.
- Montibeller, G., Franco, L. A., Lord, E., & Iglesias, A. (2009). Structuring resource allocation decisions: A framework for building multi-criteria portfolio models with area-grouped options. *European Journal of Operational Research*, 199(3), 846–856.
- Phillips, L. D., & Bana E Costa, C. A. (2007). Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing. *Annals of Operations Research*, 154(1), 51–68.
- Piketty, T. (2015). *Das Kapital im 21. Jahrhundert* (7th ed.). C.H.Beck.
- Romeike, F. (2005). Zur Historie des Versicherungsgedankens und des Risikobegriffs. In F. Romeike & M. Müller-Reichart (Eds.), *Risikomanagement in Versicherungsunternehmen*. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA.
- Sevastjanov, P., & Dymova, L. (2009). Stock screening with use of multiple criteria

decision making and optimization ☆. *Omega*, 37(3), 659–671.

Xidonas, P., Askounis, D., & Psarras, J. (2009). Common stock portfolio selection: a multiple criteria decision making methodology and an application to the Athens Stock Exchange. *Operational Research*, 9(1), 55–79.

Xidonas, P., Mavrotas, G., & Psarras, J. (2009). Equity portfolio construction and selection using multiobjective mathematical programming. *Journal of Global Optimization*, 47(2), 185–209.

Zhao, S., Lu, Q., Han, L., Liu, Y., & Hu, F. (2015). A mean-CVaR-skewness portfolio optimization model based on asymmetric Laplace distribution. *Annals of Operations Research*, 226(1), 727–739.