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Experimental Investigation of Human Decision Processes in Portfolio Decision Analysis

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Abstract

Till now operations management mainly dealt with finding appropriate models to facilitate decision making processes, but these theoretical concepts did not always help to deal with actual processes in practice. Thus the understanding of human behaviour becomes more and more important. Furthermore the behavioural aspect of the decision making process plays a big role, as everyone of us would face resource allocation situations or portfolio decisions and people always do not make optimal decisions as mathematical models would do, but rather a completely another way often based on heuristics. Therefore it is interesting to investigate how people tackle such decision making situations intuitively and which cognitive strategies they follow thereby.

This work aims to give a detailed overview about the relating literatures at first. Then decision making processes in portfolio decision situations are experimentally investigated regarding to behavioural aspects, in this case concerning knapsack problems, with the application of the methodology verbal protocol analysis. Concrete heuristics which subjects were following during the decision process could be identified and classified under the terms of certain criterions for further analysis. Hereby verbal protocol analysis helped to collect good and applicable data for determining specific behaviour of people in portfolio decision processes.

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List of Abbreviations

B	heuristic maximize Benefit
BCG	Boston Consulting Group
C	heuristic minimize Cost
ca.	circa
CAC	Consume and Check
DBC;B-C	Difference Benefit-Cost (Value-weight)
Diff	difference
e.g.	exempli gratia/for example
et al.	et alii/and others
etc.	et cetera/and so forth
i.e.	id est/that is
K	group with mental arithmetic
KP	Knapsack Problem
K&T	group with both mental arithmetic and calculator
Nr.	number
p.	page
RBC;B/C	Ratio Benefit/Cost (Value/Weight)
SAS	Solve and Schedule
T (number)	Participant (number)
TUM	Technische Universität München
TUM-BWL	Technologie- und Managementorientierte Betriebswirtschaftslehre
T&E	group with calculator or Excel
VPA	Verbal Protocol Analysis

List of Symbols

ARS_2	Averaged rank sorting metric
c	capacity of a knapsack problem
c_{item}	Heuristic-criterion-value of an item
c_{max}	Maximum heuristic-criterion-value
c_{min}	Minimum heuristic-criterion-value
DRP_1	Data-Range-Part metric without updating
DRP_2	Data-Range-Part with updating
i	Number of Iterations
j	Indicator for respective iterations, selections or deselections
n	Indicator for the respective item
p	p-Value of the t-Test
p(1/2)	decision phase
r_{item}	Rank of an item for the respective heuristic
r_{max}	Maximum rank-value for the respective heuristic
RS_1	Rank-Sorting metric without updating
RRS_2	Rank-Range-Part with updating
v	value of an item (benefit)
w	weight of an item (cost)
x	solution vector of a knapsack problem
α	Degree of optimality

1 Introduction

Kester et al. (2009) emphasized the importance of operations management and its challenges for companies. They claimed that operations management has severe consequences for a firm´s long-term competition position and as a relevant sub-field the portfolio management is not seen as a singular process but as a span of interrelated decision-making processes that aim to refine and implement the firm´s strategic goals by effectively allocating the available resources (Kester et al., 2009). As operations management mainly dealt with finding appropriate models to facilitate decision making processes, for instance portfolio choice and resource allocation problems, and these theoretical concepts did not always help to deal with actual processes in practice, the understanding of human behaviour becomes more and more important. Thus researchers began to focus on people issues, as it is significant for the success of the application of operations management tools and techniques. Furthermore the behavioural aspect of the decision making process plays a big role, as everyone of us would face resource allocation situations and people always do not make optimal decisions as mathematical models would do, but rather a completely another way often based on heuristics. Therefore it is interesting to investigate how people tackle such resource allocation problems intuitively and which cognitive strategies they follow thereby. Thus the purpose of this work is to investigate such behavioural aspects in decision processes experimentally and how well people perform with their selected heuristics.

Bendoly et al. (2006) gave a detailed review about the investigated topics dealing with experimental and behavioural research. The few existing studies in this field are e.g. the newsvendor problem analyzed in the paper of Gavirneni and Isen (2010) or the meal allocation problem investigated by Ball et al. (1998). These are both popular areas in the operations management research. To get a more detailed overview on the literature dealing with portfolio decision analysis and resource allocation problems, an extensive literature review is done in this work, forming the first major part.

Another main part of this thesis is the experimental investigation of a resource allocation problem or rather a portfolio decision problem, the so-called knapsack problem. Since there is rarely literature about knapsack optimization problems, the chair Operations & Supply Chain Management of TU Munich started research on this topic in the last years, so that the present work could continue the studies already done by Masia (2012), Tisch (2013) as well as Li and Richter (2013). Tisch (2013) has developed knapsack problem instances, each with 10 items, and conducted the experiments with the tool z-Tree, where the participants could make their decisions with this computer software independently and anonymously. Li and Richter (2013) continued his work and added the verbal protocol analysis method to the experiment setting for better following the decision and thinking processes. A further step is made here, i.e. the experiment setting of Li and Richter (2013) is modified a little bit. The knapsack instances have 15 items and are highly correlated this time. Many of the metrics applied by Tisch (2013) are adopted or refined to adapt them to the used methodology in this study. In individual sessions or interviews the subjects have to make portfolio decision regarding knapsack problems, while they are required to verbalize their thoughts during the decision-making process. The results of Tisch (2013) as well as Li and Richter (2013) can be confirmed for some part and their findings are discussed and extended. The methodology enables to analyse the portfolio planning behaviour of the subjects, as the line of reasoning for their decision-making can be always reconstructed with it. Additionally clear trails of the decision processes regarding to the giving knapsack problems are revealed and consistent results for the analysis could be obtained. The strengths and weaknesses of the methodology are also identified, as verbal protocol analysis is a relatively new method for operations management.

2 Literature Review

Operations management includes a wide range of research fields such as product development, process design and improvement, inventory management, portfolio decision analysis and supply chain management. There is always a gap between the concepts of operations management and the actual processes in practice, as the theories often ignore important characteristics of real systems and therefore are perceived to be difficult to apply in practice (Bendoly et al., 2006). Since the 1950s researchers began to focus on people issues, because the understanding of human behaviour is significant for the success of the application of operations management tools and techniques, so that more and more studies were published on the topic behavioural operations management. Thus this work investigates the decision behaviour within knapsack optimization as a special portfolio selection and resource-allocation problem which was always defined as choosing between options that differ in costs and payoffs in the literature.

Fasolo et al. (2011) wrote a report about behavioural operations management issues especially regarding portfolio and resource allocation decisions and they pointed out the relevance of these issues to the portfolio decision analysis in their review. A formal framework for portfolio decision analysis was built to help interpreting resource allocation and portfolio decisions. The authors mainly focused on intuitive heuristics and biases which are closely connected with such decision processes. They claimed cognitive or motivational failure and justifiability being the reasons for the violation of normative models that explain resource allocation situations (Fasolo et al., 2011). The study is important to understand how people naturally and intuitively concern the every-day-situation of allocating resources. This is a crucial aspect as the human decision behaviour studied in this work is also of intuitive nature. There are two different types of biases which result from the institutional, legal or political environment: individual biases (cognitive and motivational factors) and organizational biases, as the first ones were outlined from laboratory work and the organizational ones from real experiences of the authors (Fasolo et al., 2011). Suboptimisation, partition dependence, various forms of status quo bias and scope insensitivity belonged to the individual biases and justifiability (5 arguments: equalisation, anchoring, minimum requirement, demonstrable benefits and appeal to champions) formed part of the organizational biases (Fasolo et al., 2011).

Loch and Wu (2007) intensely investigated issues of behavioural operations management in their book and reviewed many relevant literatures regarding to this. They outlined important aspects of behavioural operations management and tried to define this concept including all of these aspects which looked as follows (Loch and Wu, 2007, p. 15):

OM is concerned with the study of the design and management of transformation processes in manufacturing and service organizations, building mathematical theory of the phenomena of interest and testing the theory with field data (derived from surveys, databases, experiments, comparative case studies, ethnographic observations, etc.). Behavioural Operations Management is a multi-disciplinary branch of OM that explicitly considers the effects of human behaviour in process performance, influenced by cognitive biases, social preferences, and cultural norms.

The authors then focused on individual decision making heuristics and its biases, as this part of behavioural operations management helped to understand employee performance during operational processes. As Kahneman (2003) set intuitive judgments between automatic perceptions and deliberate reasoning and categorized intuition and reasoning as two thinking systems (Figure 1), these judgments of decision makers were related to diverse heuristics which could sometimes result in systematic biases (Loch and Wu, 2007). The importance of such heuristics is why they are a focal point in this work.

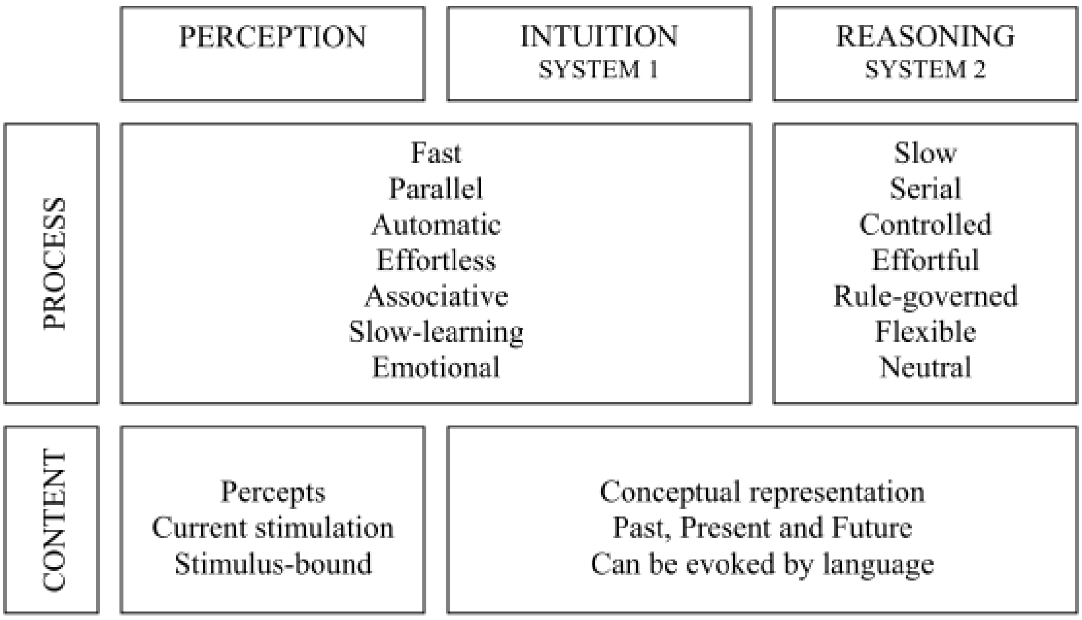

Figure 1: The intuitive and reasoning system (Kahneman, 2003)

Bendoly et al. (2006) described the importance and benefits of experimental investigations in the context of behavioural operations management and reviewed diverse literature from 6 different journals between 1985 and 2005 to develop a framework for identifying the types of behavioural assumptions made in analytical operation management models. The investigated issues could be assigned to the areas inventory management, production management, product development, quality management, procurement and strategic sourcing, and supply chain management. The assumptions were grouped into "intentions", "actions" and "reactions", whereas most literature belonged to the "actions" assumption (Bendoly et al., 2006). The authors also mentioned a possible categorization of the behavioural research literature following the types of experiments: industrial, laboratory and situational experiments and in conclusion they identified future research opportunities (Bendoly et al., 2006).

Hämäläinen et al. (2013) also highlighted the importance of behavioural operational research and investigated particularly behavioural aspects related to the use of operational research methods in modeling, problem solving and decision supporting, as the insights could improve the problem solving process and help to make better decisions. They conducted four experiments with 11 different questionnaires about a department store task at the university to find out how people understand and make decisions regarding dynamic systems. The results showed that the communication phase of operational research processes was highly sensitive to various behavioural effects such as priming and framing effects (Hämäläinen et al., 2013). The findings were important to improve operational research practices.

Resource allocation is a much discussed topic that has been analyzed from many different perspectives. Operations management researchers represent one of these perspectives and in the last years more and more of them developed concrete theories as well as linear and nonlinear techniques to handle resource allocation problems especially within portfolio selection decisions. Thus behavioural issues in portfolio choice and resource allocation problems are tightly affiliated with each other and the investigation of them is relevant for the final portfolio decision analysis (Fasolo et al., 2011). A proper understanding of human behaviour and biases regarding to this would help to improve the portfolio selection process and thereby maximize the outcome. The present thesis intends to make an extensive literature review by roughly grouping relating works into general resource allocation problems of real objects and abstract financial portfolio selection cases. There is a general characterization about decision analysis subsequently. This would build a useful theoretical framework for the experimental investigation of human decision processes in portfolio decision analysis in this work.

2.1 Financial Portfolio Optimization

As portfolio management played an important role for yielding profits as well as for a firm ́s long-term competition position on the markets, portfolio decisions should be made carefully and placed in the context of the whole portfolio and the achievement of strategic goals of the management. Strategic alignment, value maximization and balance are the three wide-ranging goals found by Cooper et al. (2001).

To assess probabilities and to predict values which always occurred in asset management people always made intuitive decisions based on different heuristics which could result in systematic biases. This phenomenon also concerned portfolio decisions and Tversky and Kahneman (1974) experimentally investigated the possible heuristics and biases in such decision-making processes within a mathematical model under uncertainty. They conducted diverse experiments with students and identified three types of heuristics: representativeness, availability and anchoring and adjustment. The representativeness heuristic was applied when decisions were based on the similarity between objects and could lead to biases such as the gambler's fallacy, the conjunction fallacy, and misperceptions of randomness; the availability heuristic (information ́s availability, retrievability and vividness) prompted people to look at the frequency or the probability of an event which would lead to overestimation of the probability of catastrophic events; the last identified heuristic anchoring and adjustment which was mainly applied in numerical predictions meant that people always tended to make decision adjustments from a relevant anchor value, so that these estimates could be easily manipulated (Tversky and Kahneman, 1974). A better understanding of these heuristics and biases would lead to better decisions under uncertainty.

Although expected utility theory was always applied to the analysis of portfolio decision making under uncertainty and risk, Kahneman and Tversky (1979) found examples of choice problems in which, as they said, preferences systematically violated the axioms of expected utility theory. These findings came from responses of students and university faculty to hypothetical choice problems, e.g. the purchase of different insurance programs. The investigation results helped the authors to develop the alternative prospect theory which set value for gains and losses instead for final assets and decision weights for every alternative choice or rather uncertain outcome (Kahneman and Tversky, 1979). They also claimed that the value function was (1) defined on deviations from the reference point; (2) generally concave for gains and commonly convex for losses; (3) steeper for losses than for gains (Kahneman and Tversky, 1979, p. 279). The new theory built a better framework for dealing with risky choice problems such as asset decisions.

Rapoport (1984) dealt with financial portfolio planning problems and used a computer-controlled, discrete-time, multistage betting game (MBG) to study how portfolio decisions are influenced by factors such as different investment conditions and the amount of available capital. The portfolio selection tasks in the experiments contained both risky and riskless alternatives or assets and the 28 subjects had to make about 400 betting and savings decisions in each case. Thereby Rapoport (1984) intended to investigate (1) the effect of changes in capital on the proportion of capital put in savings, and (2) the effect of the investment conditions (favorable vs. unfavorable) on saving behaviour. He found out that (1) the proportion of capital saved increases with the amount of capital on hand, and (2) the proportion of capital saved decreases with practice when the investment conditions are favorable and increases with practice when they are unfavorable. In the experiment the investment conditions had a significant effect on the portfolio decisions made by the subjects, just as the portfolio decisions influenced by the experiment setting investigated in this work.

In another research Kroll et al. (1988) tested the application of the specific mean-variance model for portfolio selection. They conducted experiments with 15 knowledgeable undergraduate students who should make choices in 40 computer-controlled portfolio selection problems with each including two independent risky assets and were provided with information about these assets. The independent variables manipulated in the laboratory experiments were the distributions of risky assets, the initial investment capital and the amount of practice. It came out that there were a high percentage of inefficient mean-variance portfolios which did not decrease with practice, a big amount of requests for useless information, many switches between the two risky assets and sequential dependencies (Kroll et al., 1988). Cognitive biases and intuition could be a reason. The authors suggested that a more general model would provide a more adequate account of portfolio decision behaviour than the mean-variance model, e.g. a focus on the human heuristics.

As Lipshitz and Strauss (1997) also investigated how decision maker or managers of a company dealt with uncertainty of portfolio planning problems, they analyzed 102 self-reports of naturalistic decision-making situations under uncertainty from students, with an inclusive method of classifying conceptualizations of uncertainty and coping mechanisms developed from related literature. Three types of uncertainty could be identified from the analysis results: inadequate understanding, incomplete information and undifferentiated alternatives; and five strategies of coping were applied by the subjects: reducing uncertainty, assumption-based reasoning, weighing pros and cons of competing alternatives, suppressing uncertainty and forestalling (Lipshitz and Strauss, 1997). Inadequate understanding was mainly solved by reduction, incomplete information by assumption-based reasoning and undifferentiated alternatives by weighing pros and cons. These findings finally helped the authors to develop the R.A.W.F.S. hypothesis or rather heuristic (Reduction, Assumption-based reasoning, Weighing pros and cons, Suppression, and Hedging) which described how decision makers conceptualize and cope with uncertainty in naturalistic settings and they suggested finally that decision makers coped with uncertainty adaptively, matching different types of uncertainty with different coping strategies (Lipshitz and Strauss, 1997). The findings could be well applied in asset selection problems.

When people had to make a decision where the outcomes of the choice alternatives were uncertain, they always needed to represent this uncertainty to base or rather support his/her decision. Thus Durbach and Stewart (2011) conducted an experiment with 28 postgraduate students to test the effects of uncertainty format on single- and multi-criteria choice by deciding about a set of investment alternatives (risky and riskless) such as funds and shares to maximize value, in terms of the quality of the final choice, the specific characteristics of the alternatives that are selected, and the difficulty experienced in making a decision. Thereby the unknown performance of each alternative with three attributes on each of the three objectives was presented to the decision makers using one of the six uncertainty formats: probability distributions; expected values with or without standard deviations; a set of five quantiles; a triangular approximation to the probability distribution (minimum–median–maximum); and a set of three representative ‘‘scenarios’’ (Durbach and Stewart, 2011). Their results showed that the use of probability distributions always overloaded subjects with information and lead to relatively poorer and more difficult decisions, while subjects found formats which had an immediate level of summary, easier to use and more profitable, such as expected values, three-point approximations and quantiles (Durbach and Stewart, 2011). This paper made a crucial contribution to the analysis of different display formats for uncertain information in financial investment situations, as a skilled application of these formats would have a big influence on the decision-making process.

Benartzi and Thaler (2001) investigated in their work whether the 1/n heuristic behaviour can be found in adults choosing how to invest their retirement savings and could confirm this. The 1/n strategy or the so-called diversification heuristic means someone simply divides the contributions evenly among the n options offered in his/her retirement savings plan. The authors used hypothetical questionnaires and cross-sectional data on retirement saving plans to examine how a particular set of investment options or rather funds being offered affects the asset allocation decisions of 180 university employees as participants. While they revealed difficult issues regarding the design of retirement saving plans, they also find out that the proportion invested in stocks depends strongly on the proportion of stock funds in the plan (Benartzi and Thaler, 2001).

In another work in the same year, Benartzi (2001) investigated the phenomenon that employees always invested a large portion of their discretionary funds in company stock, though this is a quite dubious strategy due to asset diversification. The author conducted questionnaires with 500 firms which could sponsor their retirement saving plans and the evidence could confirm this tendency. The results indicated that past returns on company stock had a substantial effect on subsequent investment decisions, even though employees were unable to predict the future performance of company stock (Benartzi, 2001). The allocations of employee ́s discretionary funds to company stock were correlated with past returns but not with future returns, which showed that employees excessively extrapolated past performance. This was consistent with the representativeness assumption of Tversky and Kahneman (1974) as mentioned above. As a result of such optimism and overconfidence, there could be substantial costs for employees as they constructed highly concentrated portfolios (Benartzi, 2001), so that it became clear that past performance should not influence present portfolio decisions.

It was always assumed that investors should hold fully diversified portfolios regardless of their degree of risk aversion. Especially for risk-averse, utility-maximizing investors, diversification for the risk-seeking part of the portfolio is optimal as diversification reduces portfolio risk from the variance of the individual securities (Barasinska et al., 2012). After many studies confirmed that many private investors hold underdiversified portfolios consisting of only a small subset of available assets, called an incomplete portfolio, Barasinska et al. (2012) examined more closely the relationship between investor risk attitude and portfolio composition. The authors used data on the asset holdings of German households collected by the German Socio-Economic Panel (SOEP) and gathered information about risk attitudes of 2628 private persons in SOEP surveys by asking respondents how willing they are to take financial risks. The scale ranged from 0 (not willing to take any risks) to 10 (fully prepared to take risks). Six different asset classes were divided into three risk categories “low-risk,” “moderate-risk,” and “high-risk” and built a measure of diversification. The other measurement for portfolio composition was to look at the number of distinct asset types of selected portfolio. Based on these categories, the authors defined seven portfolio types and modelled the relationship between the self-declared risk aversion of private investors and their propensity to hold incomplete portfolios (Barasinska et al., 2012). They could confirm the assumption that households that were more risk averse tended to hold incomplete portfolios, consisting mainly of a few risk-free assets, and also found out that a household’s propensity to acquire additional assets was highly dependent on whether liquidity and safety needs were met (Barasinska et al., 2012). This behaviour could be retrieved in the knapsack experiments, as participants tried to maximize benefit without exceeding the budget.

Mehlawat (2013) dealt with a similar asset problem. He used behavioural construct of suitability to develop a multi-criteria decision making framework for portfolio selection. Suitability performance score and financial quality score of each asset were obtained by questionnaires based upon the investor ́s ratings on the criteria. Thus investor preferences for investment alternatives were incorporated to support portfolio decisions. Together with asset quality on financial criteria also using investor-preferences instead of historical data two hybrid optimization models for managing trade-offs between financial and suitability criteria was developed. These models differed in the way the suitability goal was pursued by investors and were successfully tested on randomly selected assets to combine financial optimality and suitability by improving portfolio decisions. Different preferences reflect different decision behaviour and decision heuristics which is also applicable in our case.

As an interesting comparison Hsee and Weber (1999) dealt with cross-national differences in choice-inferred risk preferences between Americans and Chinese in their research. In the first study 209 students of both countries had to answer monetary decision problems in a questionnaire and the findings showed (a) that the Chinese were significantly more risk seeking than the Americans, yet (b) that both nationals predicted exactly the opposite - that the Americans would be more risk seeking. In the second study with 131 students from both countries the questionnaire consisted of three parts with problem scenarios in the areas investment, academic decisions and medicine. For the investment problem participants should make choice between savings or investment in stocks. It was found that Chinese were more risk seeking than Americans only in the investment domain and not in the other domains (Hsee and Weber, 1999). Thus the risk preference was one variable which had systematic cross-national variation. The authors took the cushion hypothesis as the reason for this effect, as Chinese from a collectivist society would more likely to receive financial support from family and relatives in need (Hsee and Weber, 1999). It can be derived from these findings that not only risk preference variation exists in a cross-national context, but also among every one of us, so that risk preference plays a crucial role in the resource allocation and portfolio decision processes.

2.2 Resource Allocation

Kester et al. (2009) made an extensive review on the issues project selection, termination and deletion decisions and took this information as a basis for their exploratory experiment with 19 key informants from 11 multinational firms to investigate their portfolio management decision-making genres. As a result three genres with different management practices were identified: formalist-reactive, intuitive, and integrative (Kester et al., 2009). They could be described as follows (Kester et al., 2009, p. 332):

- Formalist-reactive firms use rigid planning processes and their project selections based primarily on quantitative criteria and financial methods. Their approach toward innovation and their portfolio management practices are predominantly determined by responses to competitor actions and a focus on incremental innovation.

- Intuitive firms use incremental learning processes, emphasizing qualitative criteria and methods. They primarily rely on managerial experience in decision making. Portfolio decisions are predominantly guided by the insights of the senior managers and less by a strategic approach. Their attitude toward innovation depends on the risk profiles of the decision makers.

- Integrative firms use a combination of quantitative and qualitative criteria and multiple methods that combine rigid planning with the flexibility of learning. Their actions in portfolio decision-making are driven by a strategic vision and by a desire to obtain market leadership.

The authors claimed that integrative firms would have the best chances to be successful in the long run, as they combined their strategic goals with resource allocation processes, while still considering quantitative data.

As reasons and arguments also played an important role in the decision making, Shafir et al. (1993) took a closer look at this issue by reviewing and interpreting related decision studies and experiments manipulating the role of reasons in resource allocation settings, with most of the analyzed exploratory experiments carried out by the same authors in prior research. Because reasons had a strong link to uncertainty, conflict, context effects, and normative decision rules, decision makers in a company always relied on it to justify their resource allocation decisions to resolve possible conflicts. In their research the logic of reason-based choices were investigated and analyzed to examine the ways reasons influenced people´s decisions, so that it came out that an analysis of reasons was necessary to explain some aspects of important reflective choices. Nevertheless it could not completely replace value-based models (Shafir et al., 1993).

De Cremer and Van Dijk (2005) experimentally investigated how the role of leader affected behaviour in resource allocation situations. The first laboratory study was conducted with 81 students doing a resource sharing task in groups with different role assignment (leader and follower). Results showed that leaders took more than followers and also deviated more strongly from the equal division rule (De Cremer and Van Dijk, 2005). In the second similar study with 67 students leaders' feelings of entitlement were manipulated, by legitimating a leader´s role or not. It could be demonstrated that legitimate leaders took more from the resource and deviated more strongly from the equal division rule than non-legitimate leaders (De Cremer and Van Dijk, 2005). Leaders tended to make higher allocations to the self due to their feelings of entitlement. These effects could be also investigated in knapsack decision problems conducted with groups.

After Langholtz et al. (1993, 1994, and 1995) had already investigated two-dimensional resource-allocation problems in their earlier papers, they focused on a three-dimensional complex but commonplace resource-allocation problem in this research, with allocations made on a discrete scale and optimal solutions determined with Integer Programming, compared to prior studies using continuous scale and Linear Programming (Langholtz et al., 1997). 24 participants should allocate 75 $ and 15 h to efficiently obtain as many meals as possible from three food sources over the course of a 7-day week (Langholtz et al., 1997). The authors found out that the added complexity did not influence the overall performance of the selection behaviour and that many findings of their previous research also applied to this complex three-dimensional problem: the subjects achieved solutions which are 85-90% of the optimal ones, they always spent early and reduced their consumptions before the week was out, and they tended to schedule equally among the food choices (Langholtz et al., 1997). The results are partly comparable with the decision strategies participants applied in knapsack experiments of this work.

Ball et al. (1998) intensely investigated the used strategies of people for solving resource-allocation problems, while they made intuitive decisions. They continued with the research of Langholtz et al. (1997) and in the similar experiments 20 participants were again required to make daily meal choices to maximize the number of meals they could obtain in a 7-day week when given a fixed amount of resources (given money and time) and unlike last experimental settings the research methodology verbal protocol analysis was applied this time to allow detailed analysis of the thought processes and used strategies involved in making decisions for this meal-scheduling task (Ball et al., 1998). The authors also extended the task to a 3D-problem to test if increased problem complexity would cause the subjects to adapt their decision strategy to cope with that. Similar findings as the ones from earlier research showed that participants preferred to use a CAC (Consume and Check) strategy that focused first on making daily meal selections with constant checking of remaining resources and an average meal allocation rate of 93,7% of the optimal amount and that the remaining subjects tried to use the SAS

(Solve and Schedule) strategy to determine the maximum meals possible in a week before scheduling meals on a daily basis with calculations performed before any daily selections were made and an average meal allocation rate of 95,7% of the optimal amount (Ball et al., 1998). The SAS strategy did a better performance in the 2D case, but only a limited degree of strategy adaption could be identified from the 2D to the 3D problem, while the authors suggested that CAC strategy would be more successful in a more complex task setting (Ball et al., 1998). Altogether the results were consistent with existing findings from other resource-allocation literature of them, namely that people were very good at consuming nearly all their allocated resources.

While the last two papers dealt with resource allocation problems where the goal was to maximize payoff with limited resources, Gonzalez et al. (2002) extended previous research and built an experiment design where the goal was to achieve a fixed objective while minimizing the consumption of resources. 42 students were asked to find the optimum way to schedule flight hours for two different types of aircraft, each with differing personnel and fuel requirements under conditions of certainty, risk, and uncertainty. A computer provided the participants with the instructions for performing the resource-allocation problem, the resource requirements and costs for each aircraft, and the daily constraints. Their experiment findings showed that participants could solve such resource allocation problems surprisingly well, performing best under certainty and worst under uncertainty (Gonzalez et al., 2002).

Armstrong and Brodie (1994) focused on methods supporting portfolio selections in their study. Many managers believed portfolio planning methods such as diverse matrix methods to be an effective technique for strategic decision making in companies, so that these methods are widely applied in the recent 20 years, though it did not find any empirical evidence to support the use. Armstrong and Brodie (1994) identified this problem and wanted to investigate the effect of matrix methods on the decision making process. They conducted laboratory experiments based on one of the matrix methods, the Boston Consulting Group (BCG) matrix and found out that decision makers were misled by the use of this method when they made an investment decision (Armstrong and Brodie, 1994). The BCG matrix measures market attractiveness by market growth rate and it assesses the firm's ability to compete by its relative market share. But the authors showed that its application may lead managers to make decisions that are less irrational than those they make when using unaided judgment to maximize profit, with only 13% of the 1015 subjects who used the BCG matrix in their analysis invested in the obviously more profitable project (Armstrong and Brodie, 1994). Thus it was recommended for the future to make portfolio planning decisions without matrix methods which is also considered for the present portfolio decision task.

Many research about resource allocation compared optimal possible performance with observed performance in these decision situations. Busemeyer et al. (1986) continued the research on the investigation of learning effects with respect to such resource allocation problems, i.e. how subjects learned from outcome feedback and thus tried to improve their decision policies. In their study 64 subjects should work for a company that required three tasks and they had to maximize their salary each year based on the allocated time to each of these three tasks in 50 training trials (Busemeyer et al., 1986). Two of the eight factors (prior knowledge and local objective functions) that influenced the learning process were manipulated in the experiment and a learning principle called hill-climbing was used for interpreting the results. The authors showed in the end that the learning process was efficient when there was no local maximum (Busemeyer et al., 1986). Thus this paper delivered a clue to investigate possible learning effects in the knapsack problem setting.

Many research proposed that sunk costs played a big role for the decision whether to continue investment in an ongoing project, e.g. Garland (1990) found out that the willingness to continue with the investment had a linear relationship with the sunk costs. But sunk costs are often confounded with the degree a project is completed. Conlon and Garland (1993) intended to investigate this issue more closely and conducted two laboratory experiments with varied information about both sunk costs and project completion. Their results showed in the end that degree of project completion may dominate any sunk cost effects that are present in resource allocation decisions (Conlon and Garland, 1993).

Sawyer (1990) dealt with effects of risk and uncertainty on judgments of the function form and on allocation decisions related to the judged function forms, as other research on decision theory with binary choices suggested that these had separate and distinguishable effects on judgments and on the choices made based on those judgments. He conducted laboratory experiments where over 200 subjects should illustrate the form and variance of the cue-criterion relationship in two one-time immediate retention tasks. The tasks were manipulated with two levels of risk and two levels of ambiguity. Te results showed that the tasks were judged as more linear than the actual tasks when learned under uncertain conditions and that decisions to allocate time across the two activities were biased in the direction of the more certain associations (Sawyer, 1990).

To test whether people undertake costly actions to appropriate a potentially divisible resource, Shupp et al. (2013) conducted an experiment to compare individuals' decisions across three resource allocation contests which are isomorphic under risk-neutrality, named the probabilistic single-prize contest, the probabilistic multiple-prize contest, and the deterministic proportional-prize contest. The lotteries ran in five experimental sessions, with a total of 104 subjects. There was evidence that subjects tended to make lower expenditures in the probabilistic single-prize contest than in the other two contests. While the aggregate results indicated similar behavior in the proportional-prize and multi-prize contests, individual level analysis showed that the behavior in the single-prize contest is more similar to the behavior in the multi-prize contest than in the proportional-prize contest. Furthermore the findings suggested that loss aversion was correlated with behavior in the single-prize and multi-prize contests where losses were likely to occur, but not in the proportional-prize contest where losses were unlikely.

2.3 Decision Analysis

For a better understanding of the general decision analysis process, several papers are reviewed in the following to illustrate important aspects which should be also considered for the portfolio decision analysis of the present study.

Samuelson and Zeckhauser (1988) investigated status quo effects in the decision-making processes. They reviewed a series of decision-making experiments designed to test these effects and found out that subjects were strongly affected by such status quo framing, as the stronger was an individual's preference for a selected alternative, the weaker was the bias and the bias increased relatively with the number of choice alternatives (Samuelson and Zeckhauser, 1988). The authors thought that the status quo served as a psychological anchor for the subjects, i.e. the stronger the individual's previous commitment to the status quo, the stronger the anchoring effect. They could experimentally confirm all their considerations using questionnaires with different decision questions and a given set of choice alternatives which were answered by altogether 486 students (Samuelson and Zeckhauser, 1988). The founded effects could be well applied for some economic phenomena like the difficulty of changing public policies and preferred types of marketing techniques (Samuelson and Zeckhauser, 1988). Besides the results also delivered a reason for the behaviour why most of the participants always used the same heuristic for the knapsack task as in their previous experiments.

A basic principle of rational choice claimed that an individual´s preferences towards (and decisions about) objects should only depend on the features or attributes of those objects, and not on extraneous, irrelevant factors. Delquié (1993) investigated violations of this principle, the so-called preference reversals, in particular which role the response mode played in certain types of preference reversals. He generalized the experiment design of Hershey and Schoemaker (1985) to control for framing effects and study biases on a larger scope. The results showed that biases did not disappear in the absence of framing, instead they revealed a clear and pervasive bias occurring under more controlled experimental conditions than previously known: direct trade-offs between two attributes *X* and *Y* were biased depending on whether *X* is traded off against *Y*, or *Y* traded off against *X* (Delquié, 1993). This provided strong support for scale compatibility in riskless and risky decision making.

As value trade-offs adequately express a decision maker´s values, they are essential both for good decision making processes and for insightful analyses of multiple-objective decisions. In his work Keeney (2002) assessed 12 common mistakes that individuals typically make in expressing and representing value trade-offs. This information was then applied for determining a useful set of value trade-offs. Keeney (2002) developed four steps from practical experience with applications requiring value trade-offs which should help people to identify the least desirable alternatives and avoid any logical mistakes.

Jacobi and Hobbs (2007) developed a model for estimating and correcting attribute-weighting biases in decision processes that result from the use of value trees when structuring value function weight elicitation. This model was based on the suggestion that people always employed an anchor-and-adjust heuristic. In their case study 11 managers (planners or midlevel executives) from Centerior Energy of Ohio were introduced to multicriteria decision-making methods for quantifying environmental externalities and other objectives in long-run electricity generation and conservation planning (Jacobi and Hobbs, 2007). Then they applied the knowledge in a brainstorming session and identified 15 planning alternatives wherefrom attribute weights were elicited. The data were then used to illustrate the existence and correction of the value tree-induced attribute-weighting biases with the use of their proposed model (Jacobi and Hobbs, 2007). The results confirmed the hypothesis that a bias existed that was consistent with anchor-and-adjust heuristic.

To enable a comparison between the two visualization methods heatmaps and parallel coordinates for interactive portfolio selection Kiesling et al. (2011) conducted experiments with 96 business administration students. The participants should solve a familiar portfolio selection problem, namely selecting courses for the forthcoming semester. Thereby the two visualization methods differently manipulated the information presented for the students, so that these two approaches could be compared by means of subjective measures such as user satisfaction or understanding of the problem, as well as by objective measures referring to effort, convergence, and the process structure (Kiesling et al., 2011). The results of the decision analysis showed a better objective performance of subjects who used the parallel coordinates visualization and that the choice of visualization method also had a considerable impact on the users' subjective experiences when using a decision support system for portfolio selection (Kiesling et al., 2011). Furthermore the authors indicated that decision-making styles played an important role in users' attitude toward the visualization method.

An overview on the literature treated in the three areas above is given in the Table 1.

Table 1: Treated literatures in overview

Field	Title	Author(s)	Year	Key Aspects
Financial Portfolio Optimization	Judgment under Uncertainty: Heuristics and Biases	Tversky and Kahneman	1974	Decision heuristics and biases; Asset management
	Prospect Theory: An Analysis of Decision under Risk	Kahneman and Tversky	1979	Prospect Theory; Risky choice problems
	Effects of wealth on portfolios under various investment conditions	Rapoport	1984	Multi-stage betting game; Investment capital and conditions
	Experimental Tests of the Mean-Variance Model for Portfolio Selection	Kroll, Levy and Rapoport	1988	Mean-variance model for portfolio selection
	Coping with Uncertainty: A Naturalistic Decision-Making Analysis	Lipshitz and Strauss	1997	Uncertainty in portfolio planning problems; Coping strategies
	Cross-National Di€ erences in Risk Preference and Lay Predictions	Hsee and Weber	1999	Cross-national differences in risk preferences
	Naive Diversification Strategies in Defined Contribution Saving Plans	Benartzi and Thaler	2001	Diversification heuristic; retirement saving plans
	Excessive Extrapolation and the Allocation of 401(k) Accounts to Company Stock	Benartzi	2001	Investment in company stock; retirement saving plans
	An experimental study of the effect of uncertainty representation on decision making	Durbach and Stewart	2011	Uncertainty format on single- and multi-criteria choice
	Individual Risk Attitudes and the Composition of Financial Portfolios: Evidence from German	Barasinska, Sch äfer and Stephan	2012	Investor risk attitude and portfolio composition; portfolio diversification

	Household Portfolios			
	Behavioural Optimization Models for Multicriteria Portfolio Selection	Mehlawat	2013	Fnancial and suitability criteria
Resource Allocation	An adaptive approach to resource allocation	Busemeyer, Swenson and Lazarte	1986	Learning effects
	Effects of Risk and Ambiguity on Judgments of Contingency Relations and Behavioral Resource Allocation Decisions	Sawyer	1990	Uncertain effects on judgements
	Reason-based choice	Shafir, Simonson and Tversky	1993	Reason-based choices
	The role of project completion information in resource allocation decisions	Conlon and Garland	1993	Sunk costs; Project completion
	Effects of Portfolio Planning Methods on Decision Making: Experimental Results	Armstrong and Brodie	1994	Effect of matrix methods
	Resource-Allocation Behaviour in Complex but Commonplace Tasks	Langholtz, Ball, Sopchak and Auble	1997	Meal Scheduling problem
	Resource-Allocation Strategies: A Verbal Protocol Analysis	Ball, Langholtz, Auble and Sopchak	1998	Meal Scheduling problem; Verbal protocol analysis
	Minimizing cost in resource-allocation decisions	Gonzalez, Langholtz and Sopchak	2002	Aircraft flight hours scheduling; Minimizing cost
	When and why leaders put themselves first: Leader behaviour in resource allocations as a function of feeling entitled	De Cremer and Van Dijk	2005	Role of leader in resource allocation situations

	Portfolio decision-making genres: A case study	Kester, Hultink and Lauche	2009	Portfolio management practices; Project selection issues
	Resource allocation contests: Experimental evi-dence	Shupp, Sheremeta, Schmidt and Walker	2013	Isomorphic resource allocation contest under risk-neutrality
Decision Analysis	Status quo bias in decision making	Samuelson and Zeckhauser	1988	Status quo in decision making processes
	Inconsistent trade-offs between attributes: New evidence in preference assessment biases	Delquié	1993	Preference assessment biases; Scale compatibility
	Common Mistakes in Making Value Trade-offs	Keeney	2002	Mistakes; Value trade-offs
	Quantifying and Mitigating the Other Value Tree-Induced Weighting Biases	Jacobi and Hobbs	2007	Attribute weighting biases; Anchor-and-adjust heuristic
	An Experimental Comparison of Two Interactive Visualization Methods for Multicriteria Portfolio Selection	Kiesling, Gettinger, Stummer and Vetschera	2011	Visualization methods for portfolio selection

3 Theory of the Experimental Framework

3.1 Knapsack Optimization Problem

As this master thesis deals with human behaviour within portfolio decision and resource allocation problems, the results are based on laboratory experiments concerning a zero-one knapsack problem. In the following a short overview is given on the basic model of knapsack problems.

The name comes from the imagination of a hitch-hiker filling up his knapsack by selecting from a set of possible objects the ones which will maximize his comfort, e.g. food, a sleeping bag etc. This situation is known as a single 0-1 Knapsack Problem (KP) which is one of the most important and most studied discrete programming problems and can be mathematically formulated as:

$$\text{maximize} \sum_{j=1}^{n} v_j x_j \tag{1}$$

$$\text{subject to} \sum_{j=1}^{n} w_j x_j \leq c, \tag{2}$$

$$x_j \in \{0,1\}, \qquad j = 1, \dots, n, \qquad \sum_{j=1}^{n} w_j > c \quad , \tag{3}$$

With the objects numbered from 1 to n, each having a weight w_j (cost) and a value v_j (benefit). The task is then to select objects $j \in \{1, \dots, n\}$, in order to maximize the sum of the weights, with respect to a capacity constraint c. It is also a binary decision case with $x_j = 1$ if j is selected and $x_j = 0$ if otherwise. Besides it should be arranged that an already selected object is not allowed to be selected again and that the sum of all given weights has to be greater or equal the capacity c. The amount of all selected items in a final solution is called a portfolio, thus this work investigates portfolio decision analysis. The 0-1 KP is an interesting study topic because 1) it can be viewed as the simplest Integer Linear Programming problem; 2) it appears as a subproblem in many more complex problems; 3) it may represent a great many practical situations, as Martello and Toth (1990) claimed by intensely investigating different knapsack problems in their book. But it is still difficult to solve such knapsack problems optimally due to the amount of time required for computing. Therefore researchers began to focus on heuristic solutions as approximation, so that intuitive decision behaviour also became an important aspect within portfolio management to better understand the decision making processes. The analysis method of the present work is based on such human decision heuristics which will be described in detail in the following chapters.

3.2 Laboratory Experiment

Katok (2011) introduced laboratory experiments and emphasized its importance for testing analytical models in operations management, as these bridged the gap between analytical models and real business problems. Especially the factors theoretical guidance, induced valuation and careful control of institutional structure made the application of laboratory studies rigorous. The author also claimed that there were three main purposes that laboratory experiments served (1) to test and refine existing theory (2) to characterize new phenomena leading to new theory and (3) to test new institutional designs (Katok, 2011). Subject recruitment methods and the experiment conduction method z-Tree as a useful computer interface were examined closely and a literature overview was given on the issue individual decision and strategic games. A visualization possibility of a knapsack experiment is shown in Figure 2. In the end Katok (2011) discussed several methodological topics related to good practices in designing and conducting good laboratory experiments, e.g. effective experimental design (focus and nuisance variables, treatment, full factorial design, a within-subjects design, dual trial design), the context (abstract frame), the subject pool (mostly students), setting incentives (induced value theory) - financial incentives always, and deception (indirect or direct; better without deception). Finally suggestions were made about future trends in the field laboratory experiments, considering how experimental work would look like.

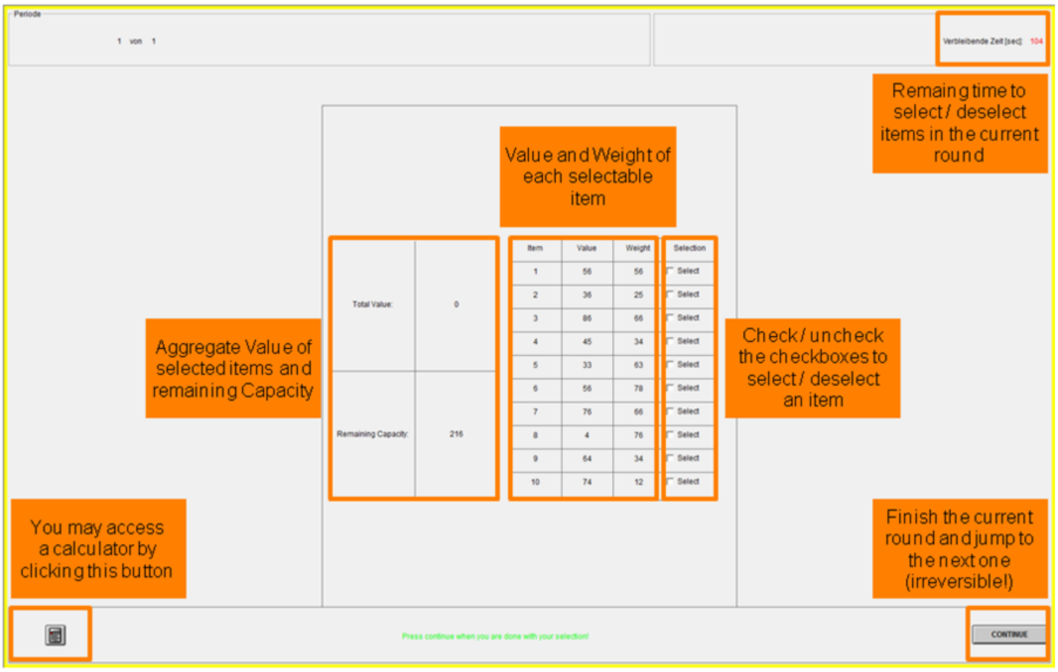

Figure 2: Experiment visualization made with z-Tree

All of these aspects helped to build an appropriate experiment design and in this work the experiments are also conducted with the computer program z-Tree and the participants should to verbalize all of their thoughts concerning the experiment task. Thus a short introduction is given about the verbalization method in the following.

3.3 Verbal Protocol Analysis

The verbal protocol analysis is a think aloud method that requires participants to verbalize or rather talk aloud his/her thoughts while solving a problem or performing a task and also state aloud the line of reasoning they are using to go from the observations to their decision. The goal of think-aloud research is to give the researcher detailed insight into the processes of working memory, as the theory of Ericsson and Simon (1980) regarding verbal protocols was based on the distinction between working memory, in which concurrent reasoning takes place in verbal form, and long-term memory, where some of the ideas from working memory could eventually be stored, not necessarily in words. To understand how these verbal protocols could be obtained, Figure 3 shows a simple model of the human cognitive system which is responsible for the thinking processes and verbalizations:

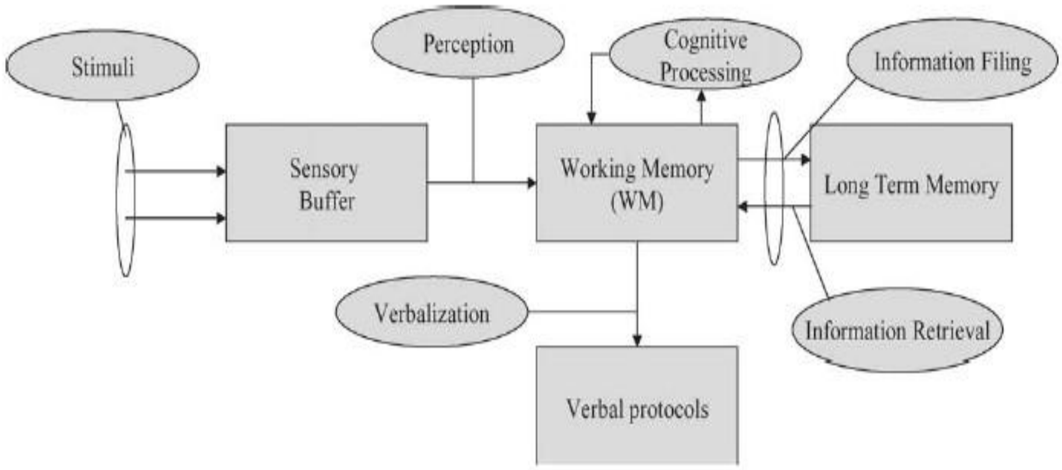

Figure 3: Model of the human cognitive system (Ericsson and Simon, 1980; Jaspers et al., 2004)

The method has been used successfully within the areas of psychology, education, and cognitive science (Ericson and Simon, 1993). It helps to analyze cognitive processes, generates direct, detailed data and consists of collecting think aloud protocols in a systematic way and analyzing the protocols to obtain a model of the cognitive processes that take place in tackling a problem (Jaspers et al., 2004). For instance it was successfully applied by diverse researchers such as Jaspers et al. (2004), Ball et al. (2008) and Gavirneni and Isen (2010) etc. It is possible that participants either verbalize their thought processes during the performance of a task (concurrent protocol analysis) or after completion of the task (retrospective protocol analysis). If the subjects forget to speak the examiner starts asking non-influencing questions ("What do you look at?" etc.) and can make notes during all experiments. The recorded audio protocols with the verbalizations are then transcribed, segmented and encoded under the terms of a developed coding scheme to provide a trace of the thought processes involved in making the decision or solving the problem, which is shown in Figure 4.

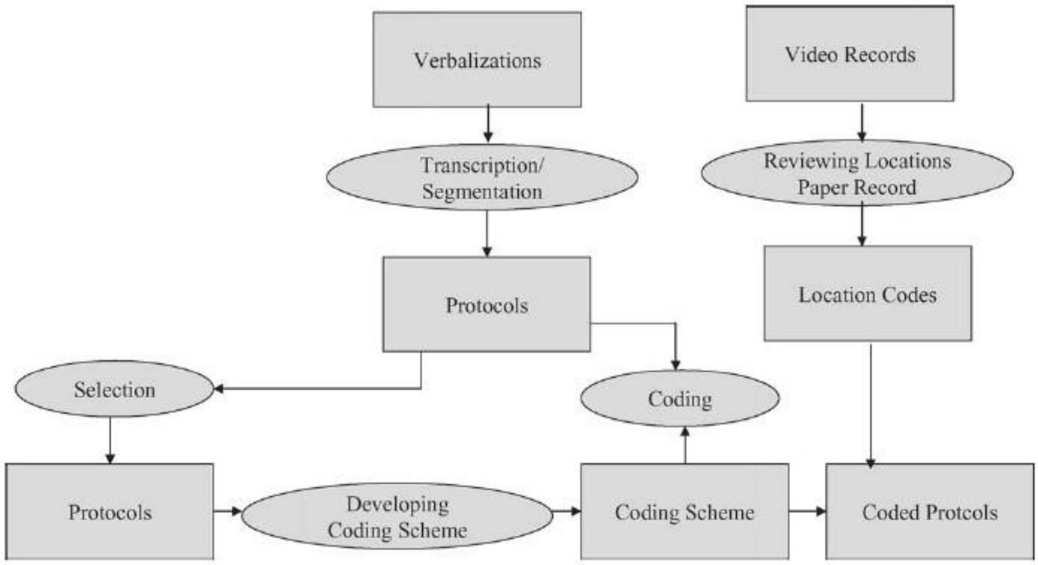

Figure 4: Schematic overview of the verbal protocol analysis method (Jaspers et al., 2004)

But the verbal protocol analysis methodology has also been criticized. Nisbett and Wilson (1977) claim that no verbalization can capture all the thoughts that a subject goes through while making a decision. The verbalization itself can also be a problem if participants are not able to express their thoughts precisely, so it might skew the observations made by the researchers. Furthermore, it might influence the decision makers to change the way how they perform, and lead to wrong conclusions.

To show how verbal protocol analysis works in practice, diverse sample applications in prior research were reported.

Already in 1976 Payne used the think aloud method to study the information search processing strategies subjects adopted to make preference choices about different furnished apartments provided with information about different attributes. The following instructions were given to the 6 subjects in the first experiment and also to the 12 subjects in the second experiment: "Whenever you start to look at a piece of information, say what you're going to look at. When making an observation about an apartment on the basis of a piece of information, describe each conclusion and the specific observations which you are using to support your judgment. Finally, please state aloud the line of reasoning you are using to go from the observations to your decision" (Payne, 1976, p. 372). The participants were paid at a fixed hourly rate. The difference of the second experiment from the first one was that the task complexity was increased and that a complete within-subjects design was used.

Bettman and Park (1980) used the verbal protocol analysis to investigate effects of prior knowledge and experience and phase of the choice on decision processes. In their study 99 housewives paid with 5 dollar had to choose between different brands of microwave ovens and simultaneously verbalize their thoughts. These subjects differed in their prior knowledge and experience with microwave ovens and due to this they were grouped into three different classes High, Moderate and Low (Bettman and Park, 1980). The moderate group did more information processing than the other groups and the subjects tended to use attribute-based evaluations in early and brand-based evaluations in later phases of choice (Bettman and Park, 1980).

In the study of Isenberg (1986) 12 general managers and 6 undergraduate students analyzed and solved a short business case. Their action plans were abstracted from the coded verbal protocols and compared with each other. The results showed a better und more goal-oriented action planning by the managers.

Highhouse (1994) dealt with decision choices under ambiguity. 45 students had to solve one of two versions of two ambiguity problems in a medical context. They were asked to record all of their thoughts before making a decision. The analysis of the verbal protocols confirmed that ambiguity-avoiding subjects ruminated more about pessimistic probabilities and that ambiguity-seeking decision makers were more likely to consider positive outcomes (Highhouse, 1994).

As already detailed above, Ball et al. (1998) also applied the method to examine used strategies for solving resource-allocation problems, more precisely a meal-scheduling task in their research.

Furthermore Benbunan-Fich (2001) used verbal protocol analysis to evaluate the usability of a commercial web site. 8 volunteer subjects were asked to send a free electronic greeting card using a selected greeting card web site. About 15 usability principles and 3 evaluation parameters were used to analyze the recorded protocols. The results stated usability problems caused by crowded content, poor navigation and cumbersome interactivity (Benbunan-Fich, 2001). The author claimed that this research method helped to reveal important usability goals and improve future web site designs.

In the research of Krahmer and Ummelen (2004) it was also about usability testing of a web site with the help of verbal protocols. Hereby the authors used two different thinking aloud approaches, one of them was the standard approach derived from Ericsson and Simon (1993), the other one from a relatively new proposal by Boren and Ramey (2000). Compared with the standard method the latter one based on more speech communication between the investigator and the subjects. Ten participants were asked to test the navigation functions of a highly non-standard web site. It came out that the different approaches did not have any effect on the process of thinking aloud, but on the task performance, with subjects in the Boren and Ramey condition completed more tasks (Krahmer and Ummelen, 2004). The evaluations of the web site quality and the detected number of navigation problems did not differ in the two approaches.

Jaspers et al. (2004) applied this method to develop an appropriate medical user interface for oncologists on computers. Four pediatric oncologists took part in the study and each of them was asked to work through 10 paper-based patient records in the context of preparing the patient visits. Their activities and think-alouds were both audio-recorded and video-recorded to investigate their information needs and search strategy. The results were used to develop a cognitive task model reflecting pediatric oncologists' task behaviour. This model served then as input for a prototype user interface which would support future work of the oncologists.

Gavirneni and Isen (2010) used verbal analysis protocols to investigate anomalies of a newsvendor problem and gained insights into the decision making processes of participants in determining the order amount. The authors were the first to apply verbal protocol analysis to inventory decision making such as the newsvendor problem and could highlight the strengths and weaknesses of this methodology for exploratory theory development. In their experiment the 21 students should decide on order quantities when the demand was random and there were costs associated with ordering too much or too little, while they were asked to verbalize all of their thoughts related to the task. The reward for participation was a flat $15 payment. The results showed that most subjects tended to focus on the basic information relevant to the decision and not on the advanced information and that they identified the precise overage and underage costs, but failed to convert that information effectively into the optimal order quantity (Gavirneni and Isen, 2010). It also became clear that the sequence of identified risk regarding to the overage and underage costs highly influenced the order amount. Hereby Gavirneni and Isen (2010) could confirm that the application of verbal analysis method helped them to understand the information-gathering process of the subjects and how this information was used to make their inventory decisions.

Altogether the method has its advantages, but also disadvantages, and it has to be adapted for each research purpose to hinder biases errors that could occur and to best trace the thought processes of decision makers, as it is the same here.

4 Methodology

4.1 Experimental Design

4.1.1 Task

The experiment is conducted with the program z-Tree. The 0-1 knapsack problem task which is visualized on the z-Tree interface is to determine optimal selection of items that maximizes the achievable sum of benefit subject to the given budget constraint. Each knapsack instance has 15 items. Values (Benefit) and weights (Cost) are allocated to each item. Left over budget is lost and does not add value to the solution in any way. The participants can see the remaining budget, achieved profit and remaining time on screen. If the last selected item exceeds the remaining capacity a warning appears and this item is deselected automatically. Items that were once chosen can be deselected again, but participants were asked to come up with a greedy heuristic they consider suitable to solve the problem in the beginning, as the use of the "Trial-and-Error" method would not deliver any significant information about some systematic decision behaviour. There is just one optimal solution in each round. Each subject has to solve three knapsack problems a 4 minutes. It is possible to change the chosen heuristic during the 3 runs. For calculations the participants are provided with a piece of paper, a pencil and a calculator. The subjects are allowed to ask questions during the sessions. They are also asked to talk aloud all of their thoughts occurring during the task performance which is important to the later verbal protocol analysis. At the end of 3 rounds they are asked to fill out a short questionnaire including their age, gender and study program and questions represented below. Then they also have to respond to some special questions of the investigator regarding the decision behaviour abnormalities of the subjects.

1. Are you familiar with the knapsack problem? Did you take part in such experiments before?

2. Are you familiar with the methodology verbal protocol analysis? Did you have difficulty to verbalize your thoughts?

3. What is your first idea how to solve the problem when you see the task?

4. Which criteria did you follow most to select the items?

5. Did you always follow the same criteria?

6. Was it a priority to use all the capacity?

7. Did the verbal protocol method help you to solve the problem?

4.1.2 Participants

The subjects are 23 students of Technical University Munich. Their study programs include mathematics, business informatics, and TUM-BWL and another one is an Erasmus student. All three mathematics students and all four business informatics students are in Master ́s study. The participants studying TUM-BWL consist of 2 graduate students and 13 undergraduate students. Most of them have already seen the “Knapsack 0-1” problem in the classroom setting or other experiments, but it is conceivable that they might have forgotten the mathematical details. Only 4 subjects are not familiar with knapsacks, yet they have taken part in similar laboratory experiments of the chair before. Although the number of subjects used in this study seems to be low it is similar to or even larger than the number of subjects used in earlier decision-making studies using verbal protocol analysis, for example Isenberg (1986) used 18 subjects, Ball et al. (1998) used 20, Krahmer and Ummelen (2004) used 10, Benbunan-Fich (2001) used 8 and Gavirneni and Isen (2010) used 21 subjects. Furthermore Kvale (1996) found that the common number of interviews in qualitative studies is 15 ±10, and Griffin and Hauser (1993) identified that 20 interviews obtained 91% of the theoretically available information.

As all participants attend lectures of the chair, they are granted extra scores for their exam as incentives for their participation. They have been told that their performance and results would give evidence if they tackle the task seriously and that they would not get any scores by performing the task unseriously. But as the experiments are conducted face-to-face with the investigator and the students get credits for their performance, it could be assured that they would give their best.

4.1.3 Experimental Procedure

In a similar study Li and Richter (2013) conducted knapsack experiments using 10 items and the verbal protocol method. There were also experiments conducted at the chair with 10, 15, or 20 items without the think-aloud method (Tisch, 2013; Dmitrij, 2013). As the think-aloud method makes the task more difficult due to the concurrent task solving and thoughts speaking, 20 items would overstrain the participants and therefore just a little step is made forward with 15 items in each round. Another reason for this decision is actually the motivation to verify and generalize the results from the experiment of Li and Richter (2013), i.e. to test whether their results also apply for a similar experiment setting, but a more complex task. Besides this study intends to compare the decision behaviour and using heuristics with the ones found in the mentioned previous works dealing with knapsack problems. On the other hand their findings should be extended, eventually finding new perspectives for future research. Thus 15 items in each knapsack instance seems to be a reasonable problem size.

It is essential that the item attributes do not manipulate the participants into choosing a certain heuristic. The used instances that would meet these requirements were provided from the chair. All three knapsack instances are highly correlated this time which means that the selection process would be more difficult than the used ones with low-correlated instances in the study of Li and Richter (2013). Pisinger (2005) stated in his research that the higher the correlation the harder the knapsack instances. Thus it is interesting to investigate whether the increased task complexity would affect the performance of subjects and lead to other decision heuristics.

The experiments take place in single sessions in a seminar room of the chair, each with one student and an investigator. Before the participants start with the three knapsack problems conducted with the program z-Tree, they are given an explanation of the task, the experiment procedure, the navigation of the z-Tree interface and some basic rules for the verbal protocol analysis. To show them how the think-aloud method works the investigator solves a little logic task herself while talking aloud about all of the thoughts occurring during the task performance. The example task is shown in Figure 5.

Warum ist am Ende 3=2? Wo ist der Fehler?

$$a + b = c \mid + (2a + 2b)$$

$$3a + 3b = 2a + 2b + c \mid - 3c$$

$$3a + 3b - 3c = 2a + 2b - 2c \mid \text{Ausklammern}$$

$$3(a + b - c) = 2(a + b - c) \mid : (a + b - c)$$

$$\underline{\mathbf{3 = 2}}$$

Record anything that came into your mind, regardless of its relevance!

Figure 5: Logic task as example for the verbalization process

The verbalization instructions are given to the subjects as follows: “The methods behind this experiment use what is commonly known as a ‘‘think aloud’’ approach. As you perform your task, please express all the thoughts that enter your mind so that they can be recorded and analyzed. Please record anything that came into your mind, regardless of its relevance. Say what you're going to look at, describe each conclusion and the specific observations which you are using to support your judgment.”

As detailed above, the subjects who are provided with paper, pen and calculator, then started to make choices from a set of 15 items in 3 experiments a 4 minutes consisting of a certain value and weight when given a fixed capacity. The task is to maximize the sum of the values of the selected items. The budget and item options obviously change in every round. To find the optimal solution it is not necessary to use the entire budget. Only abstract information is initially given to the subjects. The first idea was to give the subjects a more vivid example of the knapsack problem, like packing a picnic basket, but this was not adopted to assure that personal experience or preferences were not included in the decision process. As the participants in the study of Li and Richter (2013) had 3 minutes for a knapsack task with 10 items, the time is extended here to 4 minutes for 15 items each round.

The program z-Tree updates automatically the sum of benefit that has been achieved with every new item selection and shows the remaining budget so that the participants can fully concentrate on their main task. While each subject make item selections, operates calculations or talk about their doings, the invesitgator just intervenes when they request any information or do not speak for a long time.

In the latter case the investigator used neutral statements such as „Please keep talking“ or “What are your thoughts just now?” to remember the subjects to talk on. By the way it was also a task of the investigator to make notes if any of their actions attracts the attention or there is something which would not emerge from the verbal protocols later on.

After solving the knapsack problems the students are asked to fill out a questionnaire which is also conducted with z-Tree. The contents of the questionnaire are detailed above. In some case they were also asked special questions regarding their individual decision behaviour. The sessions are all audio-recorded and each of them takes ca. 40 minutes in average.

4.2 Encoding Process

After the experiments are completed, the recordings and the ex post questions are transcribed to text files. Then these protocols are segmented into plausible units of meaningful text or phrases. Each phrase consists of a single task-related statement. Thus the encoding process is consistent with the procedure suggested by Newell and Simon (1972). The data are coded for the purpose to reveal human decision heuristics in a portfolio decision setting and how the subjects argue their decision making processes. To start with the encoding processes 3-5 protocols are selected randomly at first and the coding scheme or rather the encoding vocabulary is then developed on the basis of them. Hereby the encoding example of Ball et al. (1998) was also taken into account, as this also dealt with a similar resource allocation problem. The final encoding scheme looks as follows:

In general: “/” means “and”

Read R ([item], [state])

Read the current state of item from task.

item = item to be affected (items in general (-), Number of item(Nr), remaining items (RNr), Benefit(B), Cost(C), Budget (BU), Time (T)); *state* = item state or property (in general (-), total budget remaining (RB), total profit gained (GB), time remaining (RT), Benefit(B), Cost(C), Benefit and Cost(BaC))

Calculate C ([item], [option], [method])

Perform a calculation on a given item(s). *item* = item to be affected (items in general (-), Number of item (Nr), remaining items (RNr)); *option* = calculation required (ratio Benefit/Cost (RBC), difference Benefit-Cost (DBC); *method* = mentally (m), with calculator (c), with Excel (e))

Decision D ([item], [choice])

Select or deselect an item.

item = item to be affected (Number of item(Nr))

choice = item choice (select item (S), deselect item (DS))

Argument/Action A ([choice/action], [argument])

Reason for an action or decision. *Choice/action* = item choice or action (no decision/change/selection ((item Number) -), select item (S), deselect item (DS), selecting Item by calculating RBC chronologically (SRBCCh), selecting item by its appearance as having best RBC (SRBCA), (possible) exchange options (Ex), searching for certain item fulfilling conditions (SI), strategy change (SC))

Argument = reason for choice (benefit maximizing (MaxB), cost minimizing (MinC), ratio maximizing (MaxRBC), difference maximizing (MaxDBC), filling remaining budget (FRB), exceeding remaining budget (ERB), time remaining (RT), no improvement possible (NIP), no more action possible (NAP), decision through comparison(DtC))

The number of the encoding vocabulary is minimized by still covering all mental processes of all subjects. All protocols are checked twice or triply to make corrections and to ensure the consistency of the encodings. Thus it is a very time-consuming step which takes ca. 2-3 hours for the whole encoding and editing process of each subject ́s file. The segmented fragments could be classified into one of the different defined vocabulary categories: statement/selection, calculation, information gathering or argumentation. The encodings are also complemented with the notes of the investigator made while the participants were busy with the knapsack problem instances, so that the whole train of thoughts and particular details of the subjects could be fully reconstructed. To clarify the encoding process an extract of a subject ́s protocol and the corresponding encoding is shown in the Figure 6.

T: Gut ich suche wieder nach guten Verhältnissen. Die 7 und 15 ist gut, also die Nummer 10. Nehme ich gleich noch die große hier oben, gefällt mir auch gut, die 1 hier. Die 14 nehme ich auch noch, dann nehme ich die 6 noch mit rein, und dann 11. Ach die ist hier ist auch in Ordnung, die Nummer 15. Ok dann nehme ich die 12 mit rein, die 9 ist auch nicht schlechter, obwohl hier die 2 ist deutlcih besser (nimmt 2). Achso ich habe gar nicht mehr so viel Budget über (noch 49 über). (am rumrechnen im Kopf). So ich nehme ich die 35 (15) weg und nehme die 79 (7) dazu. So jetzt schau ich ob ich was verbessern kann. Die Nummer 4 wäre noch ganz schön, d.h. 11 und 12 könnte ich wegnehmen, das reicht aber immer noch nicht, das lohnt sich auch nicht. Ah ich glaube ich bleibe dann dabei.

Well I am searching for good ratios again. The 7 and 15 is good, the number 10. Then I will take the big one here at the top, that´s quite good, the number 1. I take the 14 too, then the number 6 here, and number 11. The one here is also okay, the number 15. Then I will take the 12, the number 9 ist not bad, but the number 2 here is better (takes 2). Ah I don´t have too much budget left anymore. Okay I take this 35 (number 15) away and add this 79 (number 7) instead. Now I am going to take a look, can I improve it in some way...The number 4 is very well, i.e. I could take number 11 and 12 from the set, but it is not enough, it´s not worth..Ah I think I stick to it.

Experiment 3: Benefit:799, Remaining Budget: 5

1.A(SRBCA, MaxRBC)

2.D(Nr10, S), A(S, MaxRBC)

3.D(Nr1, S), A(S, MaxRBC)

4.D(Nr14, S), A(S, MaxRBC)

5.D(Nr6, S), A(S, MaxRBC)

6.D(Nr11, S), A(S, MaxRBC)

7.D(Nr15, S), A(S, MaxRBC)

8.D(Nr12, S), A(S, MaxRBC)

9.D(Nr2, S), A(S, MaxRBC/DtC)

10.R(BU, RB)

11.D(Nr15, DS)

12.D(Nr7, S), A(Ex, MaxB)

13.A(SI/Ex, MaxB)

14.A(-, NIP)

Figure 6: 1. Original text in German. 2. Translated in English. 3. Extract from a subject´s verbal protocol. Transcripts encoded using the vocabulary provided above. It is clear that this subject follows the heuristic RBC and also calculated the ratios mentally. In the end the subject tried to improve the result by searching for exchange options which would increase benefit.

The developed encoding scheme is quite similar to the one in the study of Li and Richter (2013) except a few modifications. The major difference between the two versions is the method differentiation in the calculation category, i.e. mental arithmetic is explicitly distinguished from calculating with a calculator or Excel this time.

4.3 Analyzing Process

The finished 23 codes are then analyzed regarding diverse purposes. At first the codes were checked to find useful information which was then summarized in an Excel table together with the general statistics such as the decision steps and selected items. Relevant aspects from the questionnaire and the notes are also included in this table. Altogether it contains data about selection steps, used strategy, possible strategy change, selection order of used strategy, calculation type, achieved sum of benefit, optimality of each instance for each subject, mean optimality for each subject, utilization of the remaining budget and whether gaining an overview before item selections. All these information help to reveal heuristics used to make portfolio decisions as well as biases or behaviour anomalies in their decision making processes.

On the basis of these data the subjects are classified into four groups dependent on the chosen strategy for further analysis: RBC (benefit-cost ratio), DBC (benefit minus cost), strategy-changing group (including all emerging heuristics: maximum benefit, RBC, DBC, minimum cost) and mixed heuristic group (2 or 3 heuristics are combined with each other). Optimality values, RRS_2 und DRP_2 are calculated for each subject regarding these heuristic groups. The table is also sorted by the type of calculation to enable a comparison of optimality between the groups. Further differentiation analysis has be done screening whether the participants had problems with the think-aloud method, whether this method was a help for them by solving the knapsack problem and whether they gained overview before starting with the task. The encodings are investigated closely if any results are surprising, as the decision processes can be traced in the codes. With the help of the encodings the average decision steps are calculated for all subjects and the first item selections are also analyzed with the special metric ARS_2. Last but not least the achieved benefit of each student is accumulated according to his/her selection order. Different charts are then made with these accumulated benefits due to different features such as instance, heuristic groups etc.

The analyzing process is also very time-consuming and complex. The results are discussed in the next chapter.

5 Results

5.1 Optimality and Iteration

5.1.1 Optimality α within heuristic groups

The 23 participants were divided into 4 groups depending on the heuristic they used to solve the problem.

- RBC (Ratio-Benefit/Cost) - 6 from the 23 subjects (26%) used the Benefit-Cost Ratio to make their decision
- DBC (Difference-Benefit-Cost) - Only two people chose the difference between benefit and cost for all 3 Experiments (9%)
- Strategy-Change – The main part of the participants, i.e. 10 people (43%), mixed different heuristics during the 3 Experiments. We recognized two different approaches:
    - The participants used several different heuristics within one experiment.

      Example: Start with ratio for the first item chooses, switched occasionally to the heuristic maximizing benefit and then DBC to use the remaining budget.
    - The participants started with one heuristic in the first experiment and changed their strategy in the other ones or they changed the order of the used heuristic combination.

      Example: Participants started with choosing the items according to the highest benefit for the first items and completely changed their strategy to RBC in the next two experiments.
- Mixed heuristic – 5 of the 23 (22%) students used this approach by combining 2 or 3 heuristics in all three experiments without a strategy change. For instance one student always started with DBC as the decision criterion and switched then to the RBC heuristic for the remaining selections.

Compared with the research outcome of Li and Richter (2013) there is one more heuristic this time, the mixed heuristic group. Furthermore the RBC was the dominant strategy with 60% of the participants using it in their study, while almost the half are identified as part of the strategy change group in this study. The DBC group stays similar. A reason for this could be that the instances were more difficult here and thus many subjects tried to find the most adequate strategy for selecting the items and always changed their heuristic by doing so. The increased complexity of the task also resulted in the mindset that participants needed a combination of heuristics to solve the problem.

Table 2 shows the optimality for all four groups. By comparing the values it becomes clear that the most successful strategy when it comes to find an optimal solution seems to be calculating the difference of value and weight. But here we have to keep in mind that only 2 subjects belong to the DBC group and thus the statistic is not necessarily significant. This can be confirmed with the fact that the DBC group performed as the worst one in the experiments of Li and Richter (2013). RBC and the mixed heuristic follow as the next best groups. The strategy group as the last one is also not that bad with a value of 0,94, above all it is actually the best heuristic in the first instance.

Table 2: Optimality α within heuristic methods

Optimality α	Instance 1	Instance 2	Instance 3	Average
B/C	0,941	0,953	0,974	0,956
B-C	0,947	0,989	0,964	0,967
Strategy-changing	0,955	0,93	0,936	0,94
Mixed Heuristic	0,955	0,975	0,935	0,955

The statistics just show average values which could not forecast the best approach for such portfolio decisions. For instance it occurred only twice that the optimal solution was achieved, as indicated in Figure 7. They were the participants Nr. 7 (optimal in instance 1) and Nr. 18 (optimal in instance 2) who used both the RBC heuristic respectively a heuristic combination with RBC as main part to solve the knapsack instances which is not necessary the best heuristic due to the statistics in Table 2. In the study of Li and Richter (2013) the optimal solution was much more often achieved by the subjects, which depended on the used lowly-correlated instances. Furthermore the charts show that the graph of their decision steps approximated the ideal RBC graph, especially in the case of Nr. 18. This means that both would also have good RRS_2 and DRP_2 values. It becomes very clear that the participant Nr. 18 tried in the last part of the decision process to improve his achieved benefit by exchanging options. This in turn gives evidence that the subject switched to the second decision phase which will be examined more closely later on.

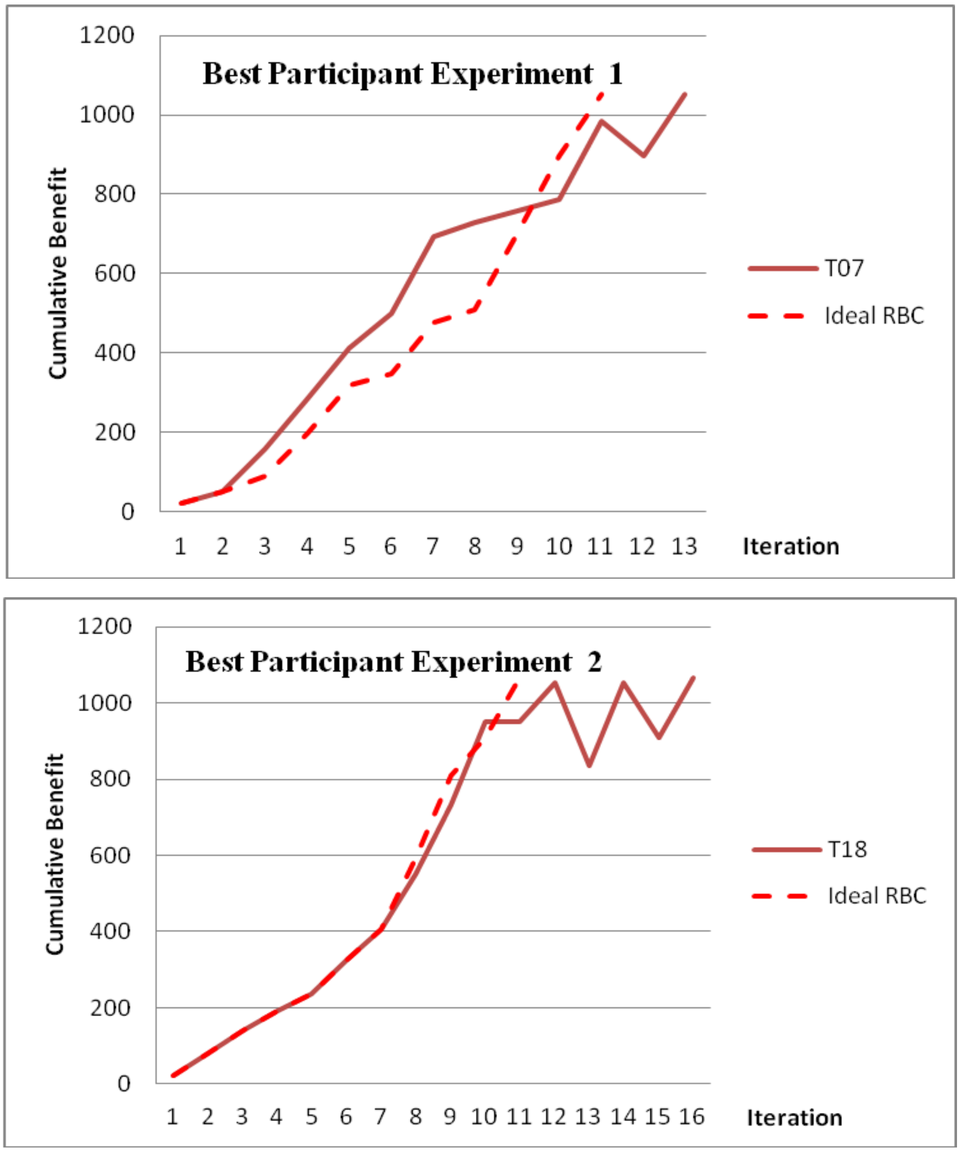

Figure 7: Best participants in Experiment 1and 2 using RBC

5.1.2 Optimality α regarding type of calculation

As already mentioned, the participants were also sorted by the way they made calculations. There are 13 subjects (57%) who calculated the needed values approximately in their head (Group K). Four students (17%) explicitly used a calculator or Excel to perform the calculations for all three experiments (Group T&E)

and six students (26%) used both mental arithmetic and calculator within each experiment (Group K&T). It is worth noting that 2 subjects asked for doing the portfolio selection with Excel, with the argument that they did the same in previous experiments of the chair in the ZIP-Pool. Both calculated the ratio of value by weight and took first the items with high ratios. An overview with the optimality performance is shown in the Table 3.

Table 3: Optimality α within calculation types

Optimality α	Instance 1	Instance 2	Instance 3	Average
K	0,958	0,976	0,934	0,956
T&E	0,944	0,902	0,989	0,945
K&T	0,932	0,928	0,952	0,937

It is surprising that the T&E group did not evidence the best performance as one should expect that exact calculations would grant the subjects to follow their heuristic accurately and thus perform well. After the corresponding encodings were studied, this phenomenon could be explained. It is because the time of two people in the T&E group ran short in the experiments so that they could not finish their selections. The bad performance of the K&T group can also be partly interpreted with this time effect and the other reason is that the task complexity and the permanent change of the calculation method caused them to disarrange their decision processes.

Many subjects selected items by its appearance as having the best criterion value, depending on which heuristic criterion they are following, without computing the precise value with the calculator, i.e. a mental arithmetic happened more or less (K group). There are 5 subjects who applied or at least partly applied the SAS-strategy with 4 of them belonging to the T&E group, and 2 subjects who applied the CAC-strategy during their decision process, although mostly not for all three instances. SAS-strategy means in this case that the subject first calculated the criterion values before he/she selected the items and in contrast to it CAC-strategy means that the subject selected items before reading all options or calculating for all items (Ball et al., 1998).

There could be three reasons for the phenomenon that more than half students tried to calculate the criterion values mentally. The first reason is that many participants would think they do not have enough time to calculate the criterion value for all items; secondly they are mostly students and owned good mathematical basic knowledge so that little mental arithmetic would not be too difficult for them. This is always enough to select the items in a right order from the one with the best criterion value to a worse item. The final reason is the dependence of the decision procedure on the task difficulty, as the complexity could have a big influence on the choice of the approach to solving a problem or whether the subjects only perform mental checks in this case. This can be confirmed with the fact that the instances feature a high complexity due to their high correlations this time and there are noticeable much more subjects who helped themselves with a calculator or Excel than in the study of Li and Richter (2013) whose instances were only low-correlated.

5.1.3 Optimality α regarding verbalizing effects

After the performance of the task the participants were asked in the questionnaire whether they were able to cope with verbalizing their thoughts or if they had problems following the procedure. They also answered the question whether the think-aloud method helped them to deal with the knapsack problem. 8 people (35%) answered that they had problems, but 4 subjects (17%) looked upon the method as a support. Their achieved optimality is compared with the contrary groups in the Table 4. In the study of Li and Richter (2013) there were only 20% people who had problems with the verbalization process. This confirmed the increased task difficulty due to the highly correlated instances once again. Actually a few students explicitly said that the knapsack experiments are more difficult than the similar ones of the chair in which they took part, as the item pairs laid quite close to each other this time.

Table 4: Optimality α regarding verbalizing influence

Optimality α	Had Problems	No Problems	Diff	VPA as help	VPA no help	Diff
All	0,957	0,946	0,011	0,929	0,954	-0,025
Instance 1	0,95	0,951	-0,001	0,958	0,949	0,009
Instance 2	0,96	0,946	0,014	0,888	0,964	-0,076
Instance 3	0,96	0,941	0,019	0,942	0,949	-0,007

To one's surprise only the statistics for instance 1 seem to be as expected. But in instances 2 and 3 subjects who had problems with VPA or did not see VPA as a help performed better than the others. Again the verbal protocols provide an explanation for this effect, with most of the students stating they would have problems with verbalizing their thoughts also said afterwards that the method did not really have a negative influence. They are just a little unfamiliar with saying and doing at the same time. Thus it comes by chance that the problem group better handled the tasks. As an example for this a figure is shown below. Although both subjects of the DBC group stated that they had problems with the think-aloud method, they performed very well.

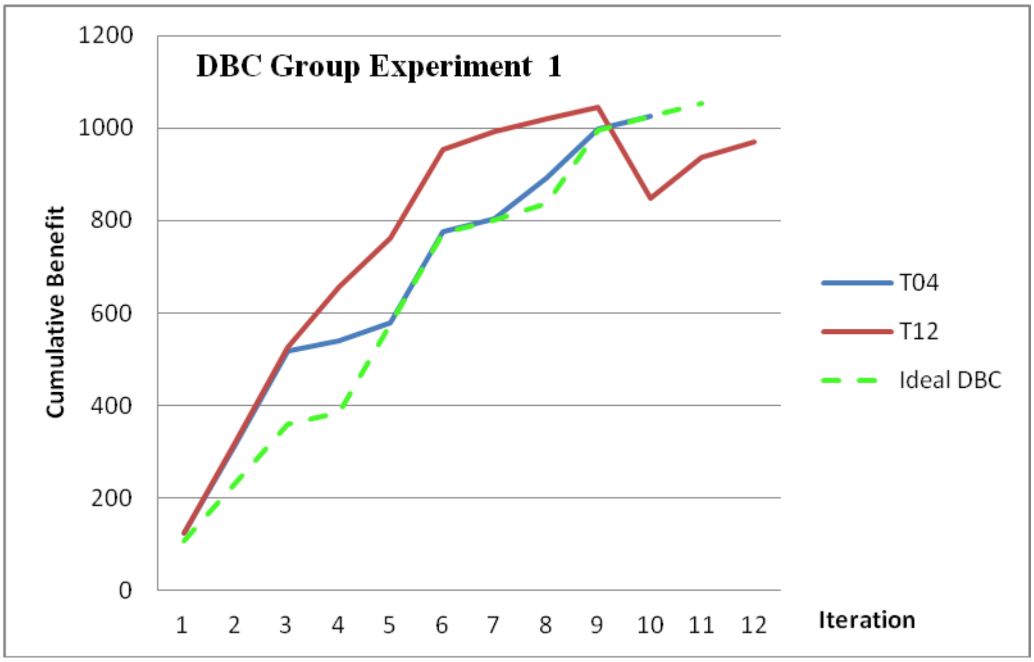

Figure 8: Performance of the DBC Group in Experiment 1

As indicated in Figure 8, the participant Nr. 8 in the VPA as Help group performed badly, as he deliberately used to approach to leave out much budget in the end for all three experiments. Subject Nr. 22 did not have enough time to select the items, because he shifted within lines by mistake while calculating the items. Therefore their performance crucially affected the group performance, as there are only 4 subjects in this group. Apart from that it can be generally assumed that using the verbal protocol procedure definitely had an influence on the performance of subjects when it comes to performing this explicit task.

Li and Richter (2013) found in their study that there were participants that appeared to feel a bit uncomfortable when supervised while performing the task. Verbalizing might not have been their major problem but having a kind of observer sitting aside made them nervous and this might have a huge effect on the performance. One of their subjects was uncommonly pressured although he knows the observer very good. To prohibit this reactivity the approach was changed a little for the present study, i.e. the subjects are not just being observed but provided with dialog possibilities with the observer. In this study they are allowed to ask questions about the presented knapsack problem while performing the task, so that the investigator was more a kind of assistance than a controller. Thus any complaints about unpleasant feelings from the subjects could not be identified here.

5.1.4 Optimality α with or without overview

From the encoded transcripts it becomes clear if subjects got an overview over the whole problem before starting on the task, so whether they would read their budget in advance and take a look at every item before making their first choice. There are 4 people in the No Overview group. The statistic in Table 5 gives evidence that subjects with overview obviously performed better in all three instances.

Table 5: Optimality α with or without an overview

Optimal-ity α	Overview	No Overview	Diff
All	0,962	0,894	0,068
Instance 1	0,955	0,929	0,026
Instance 2	0,965	0,884	0,081
Instance 3	0,965	0,867	0,098

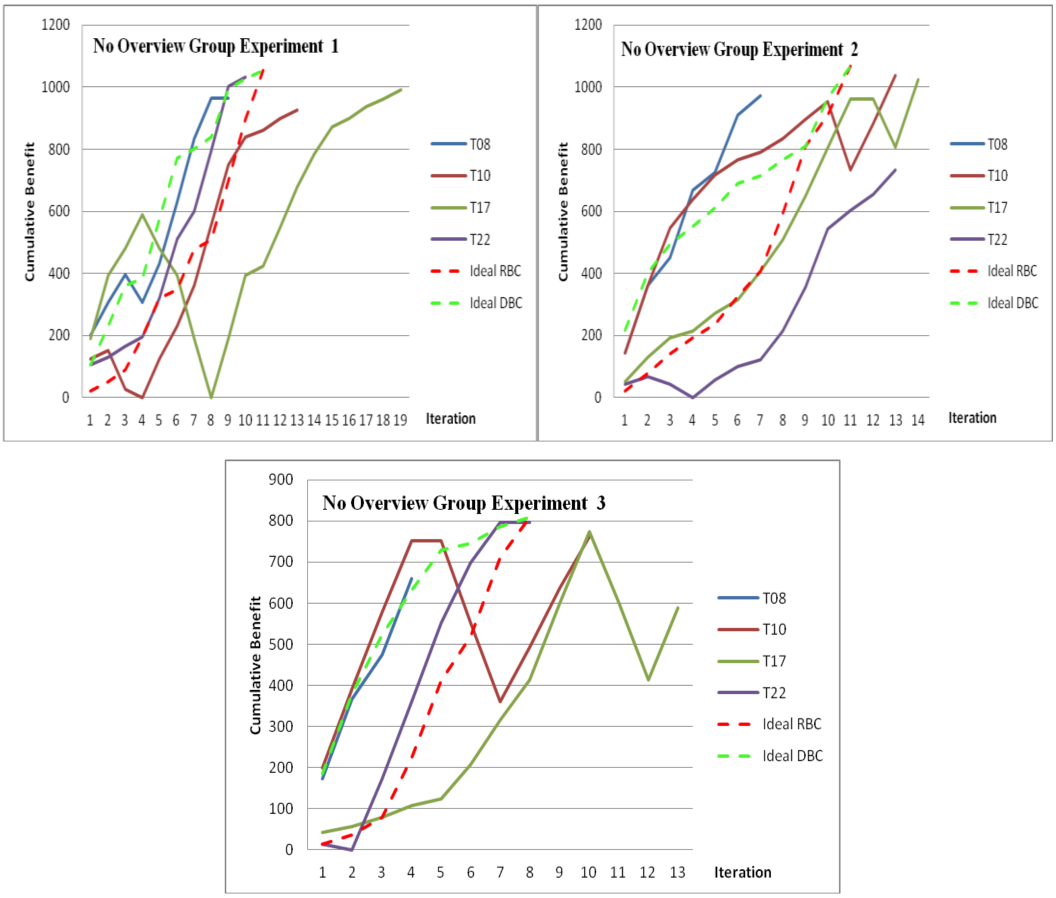

Figure 9: Performance of the No Overview Group in all Experiments

In the graphs of all three experiments with subjects that did not take an overview before starting to work on the task it is noticable that the decisions were not really determined, but rather confused and containing much deselections (Figure 9). Participants that just started working often overrun their budget before realizing how much money they actually have to spend and therefore starting to deselect and select new items. Their curve progressions do not show any regularities and are not comparable with the ideal heuristic graphs.

Furthermore three from the No Overview group are among the four worst performing subjects, with optimality values lower than 0,9. The remaining one did have problems with VPA.

5.1.5 Iterating steps

As shown in Table 6 below, the average iterating steps were also calculated for all instances on the basis of the encodings. A downward tendency can be identified. On the one hand the lowest value in instance 3 can be explained by the fact that the given budget of instance 3 is much smaller than in the other two instances. This automatically leads to less decision steps. That the subjects needed less iterating steps in the second experiment bases possibly on the learning effect, i.e. the students became accustomed to the task complexity and contents so that they could cope with the remaining experiments much better and make the decisions more fluently. Furthermore the statement of Tisch (2013) that iterating would increase with increasing correlation could be also confirmed here.

Table 6: Average iterating steps

Instance	average iterating steps
instance 1	18,3
instance 2	16,4
instance 3	14,6

5.2 Heuristics and Metrics

5.2.1 Heuristics

After analyzing the protocols and encodings for the individual experiments dealing with knapsack problem instances, it came out that the participants mainly follow four heuristics which are already partly described above:

- Choose item with maximum benefit (B)
- Choose item with minimum cost (C)

- Choose item with maximum benefit-cost ratio (RBC)

- Choose item with maximum difference of benefit minus cost (DBC)

This is similar to the outcome of Tisch (2013), but contains one more (C) compared with the results of Li and Richter (2013), as the latter authors had nobody who followed the heuristic minimum cost. However the criterions B and C only played a relatively inferior role in this work. These heuristic criterions represented above serve as a basis for the data analysis regarding to the different portfolio planning behaviour of the participants in this work. For comparing how strongly each participant follows his/her chosen heuristic, the heuristic-based metrics from Tisch ́s bachelor thesis (Tisch, 2013) were taken into account, but only RRS_2 and DRP_2 are calculated for the experiment results, because these two updated metrics make more sense than the original RS_1 and DRP_1 data without updating for evaluating purposes. In the following part a short definition is given for these two metrics.

5.2.2 RRS_2 and DRP_2

5.2.2.1 Rank-Range-Part (RRS_2) and Data-Range-Part (DRP_2) with Updating

Tisch defined RS_1 as *"RS_1 is sorting the different items of a problem instance according to the four heuristic criterions and assigns ranks from 1, constituting the most fitting, to 10, constituting the least fitting, to each item."* (2013, p. 13). In this case there are also four heuristic criterions, but the instances had 15 items, thus the ranks are from 1 to 15. The difference of the RRS_2 metric to its antecessor is that not all 15 items are considered for each iteration, but it is updated every step. Therefore updating means to take the current portfolio and the remaining capacity into account, by only considering the remaining items that are available for selection (Tisch, 2013, p. 14). Through updating the ranks are normalized and have a rank-range with values from 0,1 to 1. This allows for a better comparison and basis for analyzing how the participants make their decisions and to what extent they follow a certain heuristic criterion. So RRS_2 can be described as follows (r as ranking):

$$RRS_2=(r_{max}+1-r_{item})/r_{max.} \quad (4)$$

DRP_1 is also defined by Tisch (2013, p. 14):

$$DRP_1=(c_{item}-c_{min})/(c_{max}-c_{min}), \quad (5)$$

with c_{item} indicating the criterion-value of the particular item and c_{max} and c_{min} the maximum and minimum criterion values. Compared to RS_1, DRP_1 considers the exact spot of the item's concrete criterion-value in the criterion-value data range (Tisch, 2013). DRP_2 is calculated the same way as DRP_1, but hereby the ranks of the items are updated every iteration. Both RRS_2 and DRP_2 are averaged per subject overall iterations and are calculated on the basis of selections. These two metrics enables computing how participants select the items and how strongly they follow a particular heuristic by making portfolio decisions.

5.2.2.2 Outcome

With the verbal protocols it can be easily determined which heuristic a subject applies for every problem instance. So the metrics could be directly computed for each subject with regard to the individually applied criterion values.

Table 7: RRS_2 and DRP_2 in general and for heuristic groups

RRS_2				DRP_2			
B/C	B-C	Strategy-changing	Mixed Heuristic	B/C	B-C	Strategy-changing	Mixed Heuristic
0,85	0,8	0,88	0,91	0,73	0,76	0,78	0,93
0,86				0,8			

Table 7 gives a general overview of the RRS_2 and DRP_2 values with respect to the four strategy groups. Commonly better results were obtained compared to Tisch (2013), but the statistics were similar to those of Li and Richter (2013), for the average RRS_2 and DRP_2 values (0,86 and 0,8) in this study showed a better respectively comparable performance of the subjects in following their chosen heuristics. The maximum benefit and minimum cost criterion are not listed separately, because no subject applied these two criterions for all three instances throughout. However they could be found in the strategy-changing group and mixed heuristic group. It becomes clear that the mixed heuristic group plays the most dominant role in both cases of RRS_2 and DRP_2. The strategy-changing group follows as the second best. For RRS_2 the ratio group is still relatively dominant, but by means of its DRP_2 value the group performance is inferior to the other three strategies. This is conflictive with the findings of Li and Richter (2013), as the B/C group and the strategy-changing group showed the most dominant strategies in their experiment. The reason could be that the mixed heuristic group as a new added strategy contains B/C as a main part and thus its good performance should partly assigned to the ratio heuristic. The poor performance of the DBC group compared to the results of Tisch (2013, p. 32) possibly depends on the small quantity of participants because only two subjects followed the DBC heuristic. Therefore the explanatory power of the DBC values is not very well.

Table 8: RRS_2 and DRP_2 for 2 phases

	RRS_2				DRP_2			
	B/C	B-C	Strategy-changing	Mixed Heuristic	B/C	B-C	Strategy-changing	Mixed Heuristic
phase 1	0,88	0,81	0,87	0,9	0,77	0,78	0,78	0,91
phase 2	0,71	0,75	0,94	0,98	0,5	0,64	0,87	0,98
average phase 1	0,865				0,81			
average phase 2	0,845				0,748			

Like Tisch (2013) as well as Li and Richter (2013) two phases were identified in the selection process, too, with the phase 1 representing iterations for a first efficient solution and phase 2 always associated with item comparisons and deselections to maximize the benefit. Regarding to these two planning phases quite different results than the other two studies dealing with knapsack problems were obtained. Table 8 indicates that the metric values in the first phase are quite the same as in the general overview table, but in the phase 2 the RBC and DBC criterions decrease strongly in its importance while the other two groups have a big level-up in their domination role. Especially the mixed heuristic performs very well in both phases for both metrics. This is plausible as these two approaches always contain several heuristic criterions so that the participants could flexibly change or adapt their strategy to different purposes. In contrast to this subjects following RBC or DBC criterions easily caused bad RRS_2 and DRP_2 values when they tried to fill up their remaining budget instead of following their heuristic in the second decision phase. The general downward tendency of both metrics from phase 1 to 2 also gives evidence that subjects sometimes deviated from their selected heuristic criterion in the final phase in order to maximize their outcome. This phenomenon can also be confirmed by the fact that 18 subjects explicitly said it is important for them to use up all budget in the end for a better accumulated benefit.

Table 9: RRS_2 and DRP_2 data of subject 7

T07	strategy	Optimality α	Metric	average general	average p1	average p2
instance 1	Highest RBC	1	RRS_2	0,86	0,89	0,5
			DRP_2	0,69	0,75	0
instance 2	Highest RBC	0,996	RRS_2	0,87	0,98	0,67
			DRP_2	0,77	0,92	0,47
instance 3	Highest RBC	0,988	RRS_2	0,78	0,84	0,33
			DRP_2	0,66	0,75	0

But the performance of subjects in the RBC or DBC group regarding RRS_2 and DRP_2 does not influence their achieved optimality. An example is shown above in Table 9. The subject Nr. 7 followed the RBC heuristic and was the best performing participant among all 23 students, though his RRS_2 and DRP_2 values are just moderate.

5.2.3 ARS_2

ARS_2 values are calculated for the first selections to investigate the behaviour of the participants in the beginning. ARS_2 is defined as (Tisch, 2013, p. 35)

$$ARS_2=(r_{item,B}+r_{item,C}+r_{item,B/C}+r_{item,B-C})/4. \quad (6)$$

This metric implies all four heuristic criterions which are important in this work and it has a rank-range from 1 to 15, with 1 defined as the most and 15 as the least dominating item (Tisch, 2013, p. 35). The ARS_2 values were calculated for all 15 items of each instance and then it had to be counted how many subjects selected the respective item at the beginning to investigate the metric value for their first selections. Hereby quite different results were received in comparison to Tisch (2013) as well as Li and Richter (2013), as the most selected item in each knapsack problem instance is not the one with the smallest ARS_2 value, such as by the other authors, but items with the second or third best ARS_2 values.

Table 10: ARS_2 data and its relation to first selections

	ARS_2	First selection ratio	First selection diff	First selection change	First selection Mix	Sum	Correlation ARS_2 and Sum of first selections	p
Instance 1	8			1		1		
	10,25				1	1		
	7,75			1		1		
	5,25			5	1	6		
	6,75							
	5,5	5		1	1	7		
	10,5							
	9,25							
	7,25							
	7,25							
	11,5							
	9,5							
	8,25				1	1		
	6,25	1			1	2		
	5,75		2	2		4	-0,8039992	0,000303
Instance 2	7,5			2	1	3		
	7		1	2		3		
	7	1	1	1		3		
	6,25							
	9,25							
	6,75							
	10,5							
	8,25			1		1		
	5,5							
	6,5	3		2	3	8		
	11,75							
	6,25							
	10,5							
	7,75							
	7,5	2		2	1	5	-0,7572254	0,001078
Instance 3	7			1		1		
	5,5		1	2	1	4		
	11,75			1		1		
	6,25							
	10,25	1				1		
	7,5							
	10,25							
	8,25			1		1		
	7,25			1		1		
	6,25	5	1	2	4	12		
	6,75							
	8,25							
	10,75							
	6			1		1		
	7,25			1		1	-0,3772625	0,16567
						average	-0,6461624	

But the statements of Tisch (2013) could be confirmed that the subsequent selected items are often the three most dominating items in the ranking and if the first selection is not a dominant item, it tends to be an item with averaged ARS_2 value. Furthermore the data in Table 10 stated that the ARS_2 values are significantly correlated with the frequency of the firstly selected items in the first two instances ($p < 0,001$), but not in the last one. The first selected item is dominant in case of RBC and DBC, in case of C and RBC or in case of B and RBC and DBC, which is partly like the findings of Tisch (2013, p. 35). So it can be derived from this information that most participants always do not only consider one heuristic criterion in their decision process, but multiple criterions at the same time subconsciously. Yet they have typically a main heuristic which they are following to their knowledge.

Again the anomalies described above can be explained with the increased task complexity compared with the experiments of Tisch (2013) as well as Li and Richter (2013). As the items are highly correlated and the corresponding values and weights are closely to each other regarding different criterions, the participants always selected the items which seem to be having the best criterion value, but it is very difficult to choose the most ARS_2 dominating items without an exact calculation. The increased task complexity also caused the subjects to think more about developing an adequate decision strategy, so that the most subjects were aware of their strategy change this time, in a different way from the findings of Li and Richter (2013), whose 4 of the 6 subjects in the strategy-changing group stated explicitly that they did not change their heuristic.

But sometimes the participants even have to deviate from their heuristic or consider other criterions in their decision process, because they have e.g. a limited budget and in the end they always want to fill up the budget as much as possible and maximize the benefit simultaneously. This is not seen as a strategy change. Furthermore following a single heuristic does not mean reaching an optimal solution, not in the given three instances anyway. The optimal solution even does not consist of only one heuristic criterion, but combines many of them. Thus this behaviour does not show an underperformance, but indicates the ability of the subjects to handle the problem flexibly.

Table 11: Optimality α regarding first selections

Optimality α	Instance 1	Instance 2	Instance 3	Average
most ARS_2 dominating items as First selection	0,958	0,972	0,947	0,959
No dominating items as First selection	0,941	0,94	0,948	0,943
Diff	0,017	0,032	-0,001	0,016

Finally the optimality of subjects whose first selections were ARS_2 dominating items is compared to the optimality of the remaining subjects. The corresponding statistics in Table 11 show that the former ones performed much better. As selecting ARS_2 dominating items means to have a complete overview on the given items, this confirms in turn that the Overview group handled the task better.

5.2.4 Behavioural Aspects

While analyzing and reviewing the protocols and the corresponding encodings some conspicuous features regarding to the behaviour of the participants during their portfolio planning process were noted. Hereby the verbal protocol analysis methodology is very helpful to detect little but important details which are relevant to understand the decisions of the subjects to help outlining their chosen heuristics. The findings of Li and Richter (2013) are discussed and extended.

These are summed up in the following:

- Sometimes the subjects did not overview all items before starting selections, as they noticed an item with a good criterion value much later. This could have an impact on their performance.

- The participants always spent a long time to look at the items for comparisons of the items or mental arithmetic in the beginning.

- With increased task complexity it happened more often that subjects used a calculator or Excel to compute the criterion values.

- If the subjects used the calculator, they always computed the criterion values for all items or all remaining items.

- The behaviour and the statements of subjects showed that they did not only consider one aspect for their portfolio planning, e.g. maximum RBC, but many aspects simultaneously, even if this happened in their subconscious sometimes.

- With increased task complexity the number of subjects who changed strategy during the task performance or used heuristic combinations, increased and it became more difficult to achieve the optimal solution.

- Sometimes the subjects were not aware of their strategy change; they just switched to another heuristic.

- In the end following a heuristic criterion did not have absolutely top priority because most subjects also looked at remaining budget and tried to use this remaining budget as much as possible and to consume minimal to achieve maximal benefit at the same time. 18 subjects declared that it is important to them to fill up the remaining budget as much as possible.

- 8 subjects had problems with verbalizing their thoughts, but also 4 students stated that VPA would help them by clearing up their thinking processes.

- Subjects were good at following their once selected heuristic in general.

- With increased task complexity subjects could not exactly choose the most ARS_2 dominating item in the beginning, but this did not really influence their general performance in maximizing benefit.

- Many of the subjects could still improve their performance and they also have an idea how to do it, but did not have enough time for a modification or rearrangement.

Furthermore it can be concluded that the verbal protocol analysis is a good methodology to investigate the decision behaviour of the subjects, as some details of the process can be reproduced with it, but it does not really help the subjects to solve the decision problem. Most subjects did not have any problem with this methodology, but some have to first think about how they should explain their thoughts. Yet this could also depend on experience and practice with the verbal protocols, because they are not accustomed to verbalize their thoughts while doing a task. Verification of these findings requires further research and eventually a modified experimental setting.

6 Conclusion

This thesis experimentally investigates human behaviour in portfolio decision processes and resource allocation situations. For this purpose an extensive literature review is given on this topic at first. This review helps to understand the importance of the discussed issues and reveals research possibilities and improvement suggestions of authors in previous research regarding experiment conduction. Thus the literature review supports performing this thesis in many aspects. In second step individual experiments are conducted concerning knapsack problems with 23 people, using the methodology verbal protocol analysis to record the thoughts of the subjects verbalized aloud. On the basis of the gathered information the decisions of the participants could be retraced and the heuristics they are following to select items were revealed.

As there is not much information about this method in the operations management literature, its application was a quite new experience in many aspects. Verbal protocol analysis is proved to be easily applicable and a good tool for very detailed data collection. But there were also disadvantages by using it, such as small sample size due to the time-consuming individual sessions and the complex data analysis after the experiments. Hereby it is worth noting that the most time was spent for encodings and data analysis. Furthermore the method could distract subjects from solving the task, as 8 participants described the process of verbalizing their thoughts as difficult due to the question afterwards whether they had difficulty with the method. But in contrary to that 4 students stated that the method was a help for them to clear up their thinking processes.

Thus it appears that this methodology at least had an influence on nearly half of the subjects. The 8 participants who had problems with VPA stated that they were unfamiliar with verbalizing their thoughts during a task performance. Thus it can be concluded from this fact that the performance of subjects in their portfolio decision process depends on their practice and experience with the methodology and a negative influence of think-alouds can also lead to possible biases. However the experiment setting was modified this time to prohibit such biases, so that subjects could communicate with the investigator and feel more comfortable. Thus it cannot be stated by the analysis results of the optimality comparisons between groups that people with VPA problems performed better than others.

In general the results of Tisch (2013) as well as Li and Richter (2013) who conducted similar knapsack experiments, with or without the use of verbal protocol analysis, could be confirmed in parts. Compared with the research outcome of Li and Richter (2013) a further strategy group is identified in this work, the mixed heuristic group. Subjects belonging to this group combined 2 or 3 heuristics in all three experiments without a strategy change and performed together with the RBC group as the best groups. Unlike their percentaged distribution to different strategy groups 43% students used the strategy-changing strategy during this study as a major group, while most of the participants in their study followed the RBC heuristic. Again the DBC group with only two subjects cannot provide meaningful statistics.

Furthermore a differentiation is made between mental arithmetic and exact calculations with a calculator or Excel. The statistics show that the subjects who made mental calculations performed better than the others. But it has to be noted that the bad performance of the T&E group related to two students whose time ran short in the experiments. 8 students stated in the questionnaire that they had problems with the VPA method and 4 people perceived the method as a help which cleared up their thinking processes. As Li and Richter (2013) already stated, the subjects who had an overview over the items and the budget before starting on the task also performed better in this work.

It has to be said that compared to Tisch (2013) the average RRS_2 and DRP_2 values in the present study show a better performance of our subjects in following their chosen heuristics, with the mixed heuristic and strategy-changing group having a dominant role. As Tisch (2013) we also identified two phases in the selection process, with the phase 1 representing a first efficient solution and phase 2 always associated with item comparisons and deselections. Hereby the mixed heuristic and strategy-changing group gained more dominance in the second phase, unlike the findings of Li and Richter (2013). With the ARS_2 data analysis the decision behaviour of participants in the beginning is investigated more closely and it comes out that the first mostly selected item always have small ARS_2 values. It can be also derivde from the data that ARS_2 values are significantly correlated with the frequency of the first selected items, at least in the first two instances, and that the subjects always consider many criterions at the same time. This is consistent with the outcome in the previous studies. Additionally some special traits regarding the decision behaviour of the subjects from the verbal protocols were revealed and these findings were summarized in the last section or rather combined with the data analysis for a better understanding of the results. Thereby the results of Tisch (2013) as well as Li and Richter (2013) were discussed and extended. Furthermore the questionnaire after the experiment interestingly gives evidence that allocating the remaining budget has a high priority to most of the participants. This again has an obvious effect on the ARS_2 and DRP_2 values due to their performance for following a heuristic the whole time, but not necessarily meaning a worse performance in the metric optimality. Altogether most of the identified anomalies can be explained by the fact that the knapsack instances are highly correlated this time, resulting in an increased task complexity. This in turn affects the performance of the subjects in several aspects.

All in all the verbal protocol analysis is proved as a good methodology for experimental behaviour research concerning portfolio decision processes and on the basis of it interesting results determining clear heuristics regarding intuitive decisions in a context of solving knapsack problem are revealed. Some of these findings require further verifications in the future research with a modified experiment setting.

Reference List

Armstrong, J. S., R. J. Brodie. 1994. Effects of portfolio planning methods on decision making: experimental results. International Journal of Research in Marketing 11(1) 73-84.

Ball, C. T., H. J. Langholtz, J. Auble, B. Sopchak. 1998. Resource-Allocation Strategies: A Verbal Protocol Analysis. Organizational Behaviour and Human Decision Processes 76(1) 70-88.

Barasinska, N., D. Schäfer, A. Stephan. 2012. Individual Risk Attitudes and the Composition of Financial Portfolios: Evidence from German Household Portfolios. Quarterly Review of Economics and Finance 52(1) 1-14.

Benartzi, S. 2001. "Excessive Extrapolation and the Allocation of 401(k) Accounts to Company Stock.". Journal of Finance 56(5) 1747-1764.

Benartzi, S., R. H. Thaler. 2001. Naive diversification strategies in defined contribution saving plans. American economic review. Am Econ Assoc 91, 79–98.

Benbunan-Fich, R. 2001. Using protocol analysis to evaluate the usability of a commercial web site. Information & Management 39, 151-163.

Bendoly, E., K. Donohue, K. Schultz. 2006. Behaviour in operations management: Assessing recent findings and revisiting old assumptions. J. Oper. Manage. 24(6) 737–752.

Bettman, J. R., C. W. Park. 1980. Effects of prior knowledge and experience and phase of the choice process on consumer decision processes: A protocol analysis. ABI/INFORM Global 7(3) 234.

Boren, M., J. Ramey. 2000. "Thinking aloud: reconciling theory and practice". IEEE Transactions on Professional Communication 43(3) 261-278.

Busemeyer, J. R., K. Swenson, A. Lazarte. 1986. An adaptive approach to resource allocation. Organizational Behaviour and Human Decision Processes 38, 318–341.

Conlon, D., H. Garland. 1993. The role of project completion information in resource allocation decisions. Acad Manage J 36, 402–413.

Cooper, R.G., S. Edgett, E. Kleinschmidt. 2001. Portfolio management for new product development: results of an industry practices study. R&D Management 31(4) 361–380.

De Cremer, D., E. van Dijk. 2005. When and why leaders put themselves first: Leader behaviour in resource allocations as a function of feeling entitled. Eur. J. Soc. Psychol. 35, 553–563.

Delquié, P. 1993. Inconsistent trade-offs between attributes: New evidence in preference assessment biases. Management Science 39, 1382–1395.

Dmitrij, D. 2013. Investigating Bounded Rationality in Bahavioral Portfolio Decision Analysis. Bachelor thesis, Technische Universität München, München.

Durbach, I. N., T. J. Stewart. 2011. An experimental study of the effect of uncertainty representation on decision making. European Journal of Operational Research 214, 380-392.

Ericsson, K., H. Simon. 1980. "Verbal reports as data". Psychological Review 87, 215-251.

Ericsson, K., H. Simon. 1993. Protocol Analysis: Verbal Reports as Data. Cambridge, MA, The MIT Press.

Fasolo, B., D. von Winterfeldt, A. Morton. 2011. Behavioural issues in portfolio decision analysis: Improved methods for resource allocation. Springer, New York.

Garland, H. 1990. Throwing good money after bad: the effect of sunk costs on the decision to escalate commitment to an ongoing project. Journal of Applied Psychology 75(6).

Gavirneni, S., A. M. Isen. 2010. Anatomy of a Newsvendor Decision: Observations from a Verbal Protocol Analysis. Production and Operations Management 19(4) 453-462.

Gonzalez, R. M., H. J. Langholtz, B. Sopchak. 2002. Minimizing cost in resource-allocation decisions. Organizational Behaviour and Human Decision Processes 89, 1032–1057.

Griffin, A., J. Hauser. 1993. The voice of the customer. Marketing Science 12, 1.

Hämäläinen, R. P., J. Luoma, E. Saarinen. 2013. On the importance of behavioural operational research: The case of understanding and communicating about dynamic systems. European Journal of Operational Research 228(3) 623–634.

Hershey, J. C., P. J. H., Schoemaker. 1985. Probability versus certainty equivalence methods in utility measurement: are they equivalent? Manage Sci. 31, 1213–1231.

Highhouse, S. 1994. A verbal protocol analysis of choice under ambiguity. Journal of Economic Psychology 15, 621-635.

Hsee, C. K., E. U. Weber. 1999. Cross-National Differences in Risk Preference and Lay Predictions. J. Behav. Dec. Making 12, 165–179.

Isenberg, D. J. 1986. Thinking and Managing: A Verbal Protocol Analysis of Managerial Problem Solving. Academa of Management Journal 29(4) 775-788.

Jacobi, S. K., B. F., Hobbs. 2007. Quantifying and Mitigating the Other Value Tree-Induced Weighting Biases. Decision Analysis 4(4) 194-210.

Jaspers, M. W.M., T. Steen, C. van den Bos, M. Geenen. 2004. The think aloud method: a guide to user interface design. International Journal of Medical Informatics 73, 781-795.

Kahneman, D. 2003. Maps of bounded rationality: Psychology of behavioural economics. American Economic Review 93(5) 1449-1495.

Kahneman D., A. Tversky. 1979. Prospect theory: An analysis of decision under risk. Econometrica 47(2) 263-292.

Katok, E. 2011. Using Laboratory Experiments to Build Better Operations Management Models. FNT in Technology, Information and Operations Management 5(1) 1–86.

Keeney, R. 2002. Common Mistakes in Making Value Trade-offs. Operation Research 5(6) 935-945.

Kester, L., E. J. Hultink, K. Lauche. 2009. Portfolio decision-making genres: A case study. J. Eng. Technol. Manage. 26, 327–341.

Kiesling, E., J. Gettinger, C. Stummer, R. Vetschera. 2011. An Experimental Comparison of Two Interactive Visualization Methods for Multicriteria Portfolio Selection: Improved methods for resource allocation. Springer, New York.

Krahmer, E., N. Ummelen. 2004. Thinking About Thinking Aloud: A comparison of two verbal protocols for usability testing. Professional Communication, IEEE Transactions on, 47(2) 105-117.

Kroll, Y., H. Levy, A. Rapoport. 1988. Experimental Tests of the Mean-Variance Model for Portfolio Selection. Organ Behav Hum Decis Process 42, 388-410.

Kvale, S. 1996. Interviews. An Introduction to Qualitative Research Interviewing. Sage, Thousand Oaks, CA.

Langholtz, H., C. Gettys, B. Foote. 1993. Resource-allocation behaviour under certainty, risk, and uncertainty. Organizational Behaviour and Human Decision Processes 54, 203–224.

Langholtz, H., C. Gettys, B. Foote. 1994. Resource-allocation behaviour in harsh and benign environments. Organizational and Human Decision Processes 58, 28–50.

Langholtz, H., C. Gettys, B. Foote. 1995. Resource-allocation behaviour when gains and losses are possible. Organizational Behaviour and Human Decision Processes 64, 274–282.

Langholtz, H., C. Ball, B. Sopchak, J. Auble. 1997. Resource-allocation behaviour in complex but commonplace tasks. Organ Behav Hum Decis Process 70(3) 249–266.

Langholtz, H. J., A. T. Marty, C. T. Ball. 2003. Resource-allocation behaviour. Kluwer Academic Publ, Boston.

Li, Y., K. Richter. 2013. Experimental Investigation of Decision Making Processes in Portfolio Decision Analysis. Term paper, Technische Universität München, München.

Lipshitz, R., O. Strauss. 1997. Coping with Uncertainty: A Naturalistic Decision-Making Analysis. Organ Behav Hum Decis Process 69(2) 149-163.

Loch, C. H., Y. Wu. 2007. Behavioural Operations Management. Now Publishers, Boston.

Martello, S., P. Toth. 1990. Knapsack problems: algorithms and computer implementations. Wiley, Chichester.

Masia, A. 2012. Behavioural Issues in Portfolio Decision Analysis. Diploma thesis, Technische Universität München, München.

Mehlawat, M. K. 2013. Behavioural optimization models for multicriteria portfolio selection. Yugoslav Journal on Operations Research 23(2) 279-297.

Newell, A., H. A. Simon. 1972. Human Problem Solving. Prentice Hall, Englewood Cliffs, NJ.

Nisbett, R. E., T. D. Wilson. 1977. Telling More Than We Can Know: Verbal Reports on Mental Processes. Psychological Review 84(3) 231-259.

Payne, J. W. 1976. Task complexity and contingent processing in decision making: An information search and protocol analysis. Organizational Behaviour and Human Performance 16(2) 366–387.

Pisinger, D. 2005. Where are the hard knapsack problems? Computers & Operations Research 32(9) 2271–2284.

Rapoport, A. 1984. Effects of wealth on portfolios under various investment conditions. Acta Psychologica 55, 31-51.

Salo, A., J. Keisler, A. Morton. 2011. Portfolio decision analysis: Improved methods for resource allocation. Springer, New York.

Samuelson, W., R. J. Zeckhauser. 1988. Status quo bias in decision making. J Risk Uncertain 1, 7–59.

Sawyer, J. E. 1990. Effects of Risk and Ambiguity on Judgments of Contingency Relations and Behavioral Resource Allocation Decisions. Organizational Behaviour and Human Decision Processes 45, 85–110.

Shafir, E., I. Simonson, A. Tversky. 1993. Reason-based choice. Cognition 49(2) 11–36.

Shupp, R., R. M. Sheremeta, D. Schmidt, J. Walker. 2013. Resource allocation contests: Experimental evidence. Journal of Economic Psychology 39, 257–267.

Su, X. 2008. Bounded Rationality in Newsvendor Models. Manufacturing & Service Operations Management 10 (4) 566–589.

Tisch, A. 2013. Experimental Investigation of Behavioural Issues in Portfolio Decision Analysis. Bachelor thesis, Technische Universität München, München.

Tversky, A. 1972. Elimination by aspects: A theory of choice. Psychological Review 79(4) 281–299.

Tversky, A., D. Kahneman. 1974. Judgment under uncertainty: Heuristics and biases. Science 185 1124-1131.

Appendices

A CD is attached with all protocols, encodings, analyzing files z-Tree files and further important data.

Ehrenwörtliche Erklärung

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit selbständig angefertigt habe. Die aus fremden Quellen direkt und indirekt übernommenen Gedanken sind als solche kenntlich gemacht.

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Yi Li