Retail shelf management means matching cost-efficiently consumer demand with retail operations. As consumers demand high product availability and low prices, and retailers are constantly increasing product variety and striving towards high service levels, the complexity of managing retail business and its operations is rocketing.

Retailers need to match consumer demand with shelf supply by balancing variety (number of products), service levels (number of items of a product), and optimizing demand and profit via carefully calibrated prices. As a result the core strategic decisions a retailer must take involve assortment sizes, shelf space assignment and pricing levels. For example, offering broader assortments may limit the appropriate service levels and vice versa. Lower item prices result in a lower profit contribution per item sold, but increase demand, which needs to be replenished appropriately. Common practice in retail category management is to make decisions about these planning problems sequentially: Retailers first determine the assortment size, next allocate it to the shelves, assign prices, and then finally make arrangements for instore shelf replenishment. However, as the problems are interrelated, managing these operations in isolation may result in suboptimal decisions. The thesis consequently introduces optimization models that integrate the most relevant instore consumer choice and instore logistic effects.

Several mutually reinforcing trends have made category management one of the most critical marketing and operational decisions for retailers. German retailers and consumer goods producers recently rated optimization of product portfolio and category management as the most important task for achieving performance goals. This is not surprising as shelf space competition in retail stores is at an all-time high, driven by the competitive need to constantly introduce new products. For example, the average number of items in overall store assortments has increased by 30% since 2000.

Rigorous quantitative methods have emerged as the most promising solution to this problem. The dissertation focuses on three areas: (1) Combine assortment and shelf space planning, (2) provide efficient decision support systems for practically relevant problem sizes, and (3) integrate inventory and price optimization into shelf management.

We propose innovative models that jointly optimize assortment, space allocation and prices, viewing category profit as a composite function of price- and space-dependent demand, consumer-driven substitution and price-dependent profit. We show how our models can be implemented as a specialized knapsack problem to provide fast and practical solutions. Numerical examples based on POS-data are used to illustrate insights into planning problems. Compared to solutions generated by today's retailers' standard software our integrated optimization models:

- increase profit significantly: up to 25%
- have a considerable impact on assortment, shelf space assignment and pricing decisions: up to 3/4 of the products with different listings, facings, prices and replenishment requirements

We also use sensitivity analyses to evaluate error boundaries for consumer behavior and managerial decisions. The models can be applied by retailers and consumer goods producers.
Stellungnahme zu den folgenden bewertungsrelevanten Aspekten der Arbeit


Retailers are increasingly addressing category planning with quantitative models. The rapid development of advanced scientific models and software applications therefore has created a wide range of decision support systems. We identify and evaluate current practice as well as commercial software and match it with advanced decision support systems for assortment and shelf space management. Category management practice and research lack a holistic planning architecture and models that are based on an

- integral planning view on retail requirements and constraints (i.e., aligning planning tasks and taking into account operational constraints),

- holistically integrated consumer instore behavior (i.e., integrating decision-relevant consumer behavior based on empirical insights into planning problems), and

- comprehensive quantitative decision support (i.e., using decision support systems based on appropriate quantitative optimization models).

The challenge for retailers lies in taking an integrated view when developing demand-and supply-oriented planning models. We provide a state-of-the-art framework for integrated assortment and shelf space planning. Our rigorous quantitative approach to merchandising allows the tighter alignment of retail shelf supply with consumer demand, leading to efficiency gains and more productive shelf space. Our models can be directly transferred into retail decision making and be implemented into standard commercial software.

2. Umsetzbarkeit im Handel: Wo liegt der Anwendungsnutzen für den Handel? (max. 200 Wörter)

The research is based on commonly available retail data and focuses on developing implications for retail practice. These are:

(1) Taking an end-to-end perspective on category management: A comprehensive demand and supply chain planning from strategic to operational requirements and from shelf to supplier, for retailer and for consumer goods producers.

(2) Modeling category manager’s same-time decisions: Our profit maximization models address the category manager’s assortment, space allocation, replenishment and pricing decision problems.

(3) Providing efficient decision support systems: Despite retail managers striving to follow the mantra “retail is detail,” most retail managers have little time to consider the details of different category arrangements. Therefore, the traditional shelf space management tools generate planogram recommendations based on simplistic “rules of thumb”. We develop efficient optimization models that allow modeling practically relevant problem sizes and actual consumer behavior.

(4) Transferring into actionable models: The benefits of using shelf space models to supplement human decision making depend on how efficiently the shelf space models can run. We pave the way for decision making for typical retail categories and the implementation of such a model in commercial software applications. We also provide a pragmatic way to generate and apply relevant data for the optimization problem.
## 3. Innovationskraft der Idee (max. 200 Wörter)

The dissertation combines research areas in supply chain and category management. The positive feedback of international top journals confirms the innovative ability. One paper appeared in OMEGA (Thomson Reuters: A) and two others are in the 2\textsuperscript{nd} stage of the referee process at A-Journals.

This dissertation is the first coherent contribution that structures retail shelf space management problems from multiple perspectives and develops comprehensive quantitative decision support models. Core innovations are:

1. **Combining assortment and shelf space planning**: Assortment planning deals with the listing decision based on substitution effects. Shelf planning addresses space assignment for individual products based on space-elasticity effects. Both streams have not been integrated in the past.

2. **Integrating inventory and price optimization**: We are the first integrating restocking frequencies into category optimization models and utilizing price-elasticity to steer consumer demand.

3. **Modeling practically relevant problem sizes**: The recent past has witnessed exciting new research aimed at addressing retail shelf space management problems. However, most of them fail short in the application of actual category sizes with more than 100 SKUs per category. We are the first providing an efficient decision algorithm for such problem sizes. Our numerical examples illustrate also the benefit of an integrated decision model.

We manage both in integrating more consumer and cost effects than other models and reducing the necessary solution time by transforming the numerically-hard problem into a Knapsack-problem. All developed models have been tested with empirical data.

## 4. Angewandte wissenschaftliche Methode (max. 100 Wörter)

We study multi-product mid-term and deterministic problems that integrate facing-dependent demand effects, substitution effects, price effects, as well as inventory holding and replenishment costs. The shelf space management models are studied as mixed-integer non-linear optimization problems. We model category problems with up to 250 SKUs.

We transfer the problems into mixed-integer knapsack problems, which then allow the efficient use of optimization solvers. The models are tested with empirical consumer and retailer data to investigate the viability of the model, provide practical decision support systems, and demonstrate their superiority over commonly used retail applications.