



Dynamic product portfolio management with life cycle considerations



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ABSTRACT

We consider a portfolio of products in which each product probabilistically transitions through various life cycle stages. The evolution through these life cycle stages is impacted by both marketing support and product launch decisions, which are bound by a financial constraint in the form of restricted working capital. In the model, the joint working capital level serves to finance the portfolio expenditures and is decided a priori by the company. We use an infinite-horizon Markov Decision Process (MDP) to find the optimal decisions to coordinate the operations and finance depending on the composition of the portfolio. We find that the policy optimizing the product launch, marketing support and inventory decisions under a working capital constraint is independent of the correlation between demand levels of the products in the portfolio. We numerically demonstrate that the joint management of the products has a significant positive effect on the total profit, reducing the amount of working capital used per product. We also show that the optimal policy smooths aggregated demand levels as well as cash flows.

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1. Introduction

Companies have to continuously manage their portfolio of product lines. Some prominent examples include the mobile product lines (iPods, iPhones, iPads) managed by Apple Inc. or the product lines of DSLR cameras, such as the Rebel series managed by Canon Inc. For consumer electronics in particular, disregarding the variations in demand across different product life cycle stages may result in high operational costs due to inadequate ordering decisions and revenue shortfalls. In a portfolio of product lines, the product life cycle acquires even more relevance because the upper and lower extremes of demand and revenue may occur simultaneously in multiple product lines and thus be magnified. Therefore, companies may want to smooth the overall levels of demand and revenue by actively managing their portfolio, properly timing product upgrade launches and adequately choosing the amount and timing of marketing support. When firms are financially constrained in making needed investments yet still have to manage multiple products through various life cycle stages, achieving optimal operational and marketing decisions becomes complex. To understand how a company should combine its inventory, product launch and marketing decisions to successfully coordinate its operations and finances, we have brought together three subjects

in a unified model: product portfolio management, product life cycle and financial constraints.

We consider the product life cycle as the main source of demand dynamics, which is particularly relevant for products with short life cycles such as high technology goods (Chien et al., 2010), consumer electronics (Gerhard et al., 2011), and fashion apparel (Şen, 2008). The product life cycle is represented as a sequence of the following stages: introduction, growth, maturity, decline, and end-of-life (Van der Laan and Salomon, 1997; Ahiska and King, 2010). The transient time in these stages is extremely uncertain (stochastic). The firm can use marketing support to increase the probability of a transition to higher demand stages or to increase the resting time at the maturity stage. (The growth and decline stages can span multiple demand levels.) Therefore, within limits, companies can actively manage their product portfolio to achieve more favorable demand realizations. In fact, product life cycle management acquires real meaning at the product portfolio level since harmonizing decisions can be made to smooth aggregated demand and thus income.

Although this overall objective is clear, difficulties arise when the multiplicity of pertinent operational and financial parameters are considered. Products are characterized by varying operational cost parameters, including procurement, holding, and lost sales costs. Moreover, products can have very specific life cycle characteristics, which means each one will be in the market for different lengths of time. Furthermore, demand variability is specific to each product and to its life cycle stage. The complexity of these operational parameters should be taken into account when

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managing a product portfolio. Independent ordering decisions appear inadequate. Instead, companies may achieve higher benefits if they carefully decide when to launch each product and jointly allocate marketing support for each one to smooth total inventory and demand at the portfolio level. This product portfolio management will be particularly important when funding is constrained.

In our study, we include financial constraints in the form of a joint working capital (WC) (Protopappa-Sieke and Seifert, 2010). This WC level refers to a constant level of cash and inventory held by the company (see Section 3 for further discussion). On the one hand, WC that is too tightly constrained may limit the company's ability to purchase adequate levels of inventory to respond to demand peaks. On the other hand, WC that is too loose could increase financial costs. Ernst and Young (2010) found evidence that the top 2000 largest companies in the US and Europe have an aggregate total of up to USD 1.1 trillion in cash (equivalent to 7% of their sales) unnecessarily tied up in WC. This reference shows that a firm's WC level is an important decision for the management of a product portfolio's operational and financial costs.

In this work, we have devised an *infinite-horizon Markov Decision Process (MDP)* that includes operational and financial aspects to help manage a portfolio of product lines. With this tool in hand, we examine the following questions:

1. To what extent can active product launch and marketing support decisions improve the management of the product portfolio given homogenous and heterogenous products?
2. How sensitive are the product portfolio revenues (and product launch decisions) to financial constraints in the form of allocated working capital levels?
3. For different working capital levels, what are the most favorable product portfolio compositions?

We find that the policy optimizing the product launch, marketing support and inventory decisions under a working capital constraint is independent of the correlation between demand levels of the products in the portfolio. We numerically demonstrate that the joint management of the products has a significant positive effect on the total profit, reducing the amount of working capital used per product. We also show that the optimal policy smooths aggregated demand levels as well as cash flows.

The remainder of the paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we describe the modeling settings and our mathematical model in detail. In Section 4, we illustrate the use of our tool with numerical examples and discuss managerial implications based on our main observations. In Section 5, we summarize the main results and comment on future research opportunities.

2. Literature review

Our work touches on three important literature streams: product life cycle models, portfolio management, and working capital (WC) constraints for product portfolios.

Within the product life cycle literature, two branches may be distinguished: the first includes the product life cycle for strategic analysis, and the second studies the operational and financial coordination during product rollovers (the time when a product is substituted by an upgrade). In the literature on product life cycle for strategic analysis, Barksdale et al. (1982) explain the Boston Consulting Group's product portfolio matrix and propose to combine it with product life cycle stages to provide a more comprehensive framework for strategic analysis. Similarly, Childerhouse et al. (2002) and Aitken et al. (2003) develop a framework of

five parameters (duration of life cycle, time window for delivery, volume, variety and variability) to choose the adequate demand chain for a portfolio of products. With this framework, a UK lighting company restructured its demand chains and as a result reduced lead times and achieved better performance in sales, and customer service. The above studies show the importance of product life cycle in assembling the right product portfolio.

The product rollover literature analyzes the timing of product upgrade launches, as well as the inventory and pricing for the old and upgraded products during these transitions. Billington et al. (1998) conceptually discuss the product rollover problem. They identify that companies may choose a solo-rollover (a single product is in the market) or a dual-rollover (both products may be in the market) depending on the product and market risk of the old and the upgraded products. Wilhelm and Xu (2002) develop a dynamic programming model to decide the technology content of the upgraded product, the optimal pricing and the optimal inventory quantities. Lim and Tang (2006) find the optimal pricing and timing for both solo- and dual-rollover, and show that the choice of strategy depends on the marginal cost of both products. Li et al. (2010) analyze the product rollover problem while considering product substitution, and find that substitution increases profitability during the transition and reduces inventory needs for the old product. Most recently, Liao and Seifert (2015) analyze the optimal frequency of new product introductions and analytically prove that the speed of technology diffusion is positively associated with the frequency of the product introductions. This body of literature emphasizes the importance of product life cycle for strategic planning, and highlights the fact that companies need to achieve a balance when they have to manage two coexisting products simultaneously. However, these studies do not consider any interactions between financial and operational decisions. More importantly, they do not address how the interdependence among inventory ordering, marketing support and product launch decisions influence and react to stochastic product life cycle transitions, all of which are crucial, especially in a multi-product setting.

These limitations are partially addressed in quantitative portfolio management models reviewed by Schmidt and Freeland (1992). The following studies are particularly relevant given the scope of our work. Souder (1973) devises a nonlinear, a linear, a zero-one and a profitability index portfolio management model, and then benchmarks it with actual management decisions and outcomes. The author identifies the model that performs best at different stages of the life cycle of the R&D projects, and highlights the importance of reacting to life cycle dynamics. Fox et al. (1984) focus on project portfolio management while taking into account resource utilization interactions, outcome or technical interactions, and benefit or payoff interactions. They state that considering projects independently can lead to the possibility of "poor selection decisions and resource allocation problems." Also relevant to portfolio dynamics are the theoretical studies by Kleywegt and Papastavrou (1998, 2001) on the time-dependent and stochastic knapsack problem. These two papers analyze when to accept projects given that their rewards and times of arrival are unknown and given that there is a resource constraint for all projects. Their studies highlight the importance of uncertain dynamics on portfolio selection. Most recently, Cooper et al. (1999) make an empirical study of 205 US companies, which are subdivided into four quadrants based on the effectiveness and ease of adoption of their portfolio management method. They find that the most effective companies are those who consistently use financial and strategic methods. From this summary of quantitative models in portfolio management, it is clear that portfolio dynamics and interactions are the most important aspects for the adequate balance of portfolios. Dickinson et al. (2001) develop a

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