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Performance- and value-oriented decision support for supply chain configuration

A discrete-event simulation model and a case study of an FMCG manufacturer

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Abstract The task of supply chain (SC) configuration is to establish a product-specific SC for new products. Apart from cross-regional network aspects and inter-disciplinary factors, the problem complexity is driven by dynamics and uncertainties of short product life cycles. SC configuration affects SC performance and value creation. Hence, resulting impacts have to be measured and compared under consideration of dynamics and uncertainties. In the conceptual part of this paper, dynamics and uncertainties of SC configuration are integrated into a conceptual framework for value-based supply chain management. In the model-based part of this paper, this framework is linked to a discrete-event simulation model. The performance outcomes and value impacts of SC configuration options are empirically assessed in a case study of a fast-moving consumer goods manufacturer. The shortfalls of cost-focused decision-making without consideration of capital-related factors and non-financial aspects are illustrated.

Keywords Company value · Discrete-event simulation · Fast-moving consumer goods · New product introduction · Supply chain configuration

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1 Introduction

Supply chain management (SCM) contributes to establishing competitive advantages for companies across all industries [58]. To leverage this competitive advantage, supply network planning (SNP) can help to establish an adequate intra- and inter-organizational supply chain (SC) [54, 56, 79, 80]. This paper illustrates the integration of SNP and new product introduction (NPI) processes. In this context, the relevance of dynamics and uncertainties is pointed out, and it is exemplified that the whole product life cycle (PLC) has to be taken into account in related decision-making. Beyond this, the paper shows that the decision criteria should be broadened from mere cost efficiency or SC performance improvement to a comprehensive reflection of value creation. Furthermore, a discrete-event simulation (DES) model is proposed that supports decision-making in SNP. The model allows to assess SC performance outcomes and value impacts of SNP decisions under consideration of dynamics and uncertainties. These particular characteristics of SNP problems for NPI and the modeling approach are illustrated at a case study of a fast-moving consumer goods (FMCG) manufacturer.

With regard to the scope of the affected SC network, SNP can be categorized into SC design and SC configuration. SC design represents a comprehensive reorganization of the entire supply network which can affect all plants, distribution centers (DCs) and suppliers as well as the entire product assortment of a company [29]. Such strategic adjustments of the whole network design are capital-intense, occur rather infrequently, are quite difficult to revert, and have long-term impacts on the economic performance of a company [28, 55, 56]. In contrast, SC configuration aims at defining and establishing a product-

or category-specific SC and affects only selected parts of the supply network. However, SC configuration can result in a complicated exercise and a complex planning problem [75]. SC configuration decisions occur very frequently during NPI projects, because SCM must be aligned with the development and introduction of new products to achieve customer satisfaction and SC performance [41, 42, 62]. New or modified products have to be allocated to own plants or contract manufacturers within the existing supply network in a way that ensures cost efficiency as well as on-time and in-full availability of high-quality products over the whole PLC [29]. The complexity of resulting SC configuration problems is amplified by uncertainties and dynamics [87].

Uncertainties in an SC arise on demand and supply side [69]. They are related to ambiguous or missing information about time and quantity of demand and capacity availability, about process durations and costs or about quality specifications [6]. Higuchi and Troutt [40] illustrate the relevance of uncertain demand time and quantities for SC configuration at a case example of a new electronics toy. First, the toy manufacturer underestimated the consumer demand quantity which resulted in capacity bottlenecks, unavailable products and lost sales. Then, the decision to invest into additional production capacity was based upon an overestimated PLC length. As a consequence, the product already reached the decline phase of its life cycle when additional production equipment was made available, the production capacity strongly exceeded the demand and the investment did not result in higher sales. This case example shows that introducing products with comparably short life cycles is a critical task since there might not be enough time for major adjustments or improvements of the SC configuration later on. More generally spoken, SC configuration decisions often have to be based on rough, not finalized product concepts before the development of a product has ended. Consequently, these decisions are associated with a comparably high degree of demand uncertainties, since the actual market reception of the product is neither known at this point in time nor can be forecasted adequately based on historical data [41]. Moreover, up to 80 % of the arising product-related costs are committed at this time [2].

Dynamics in the SC can arise from order oscillations, seasonality or minimum order quantities and may result in a bullwhip effect [50, 85]. Ensuring product availability at product launch can also create internal dynamics within an SC, especially if a significant proportion of demand is expected at or shortly after product launch and thus needs to be pre-produced and distributed thereby maintaining a short time to market [41]. This phenomenon is known as pipeline filling, which is defined as the production and distribution of a product prior to product launch in order to ensure sufficient product availability across all stocking points at the launch date, i. e., at a time when product demand is fostered by strong marketing campaigns [72]. During pipeline filling activities, all stocking points are filled with a major portion of the expected annual demand before the product is actually launched in the marketplace. In this early phase of the PLC, production capacity demand strongly differs from market demands of finished products. As a result, the capacity requirements or inventory levels during the more static maturity phase of the PLC can be up to 60 % lower than during the highly dynamic product launch phase (see Fig. 1).

SCM and in particular SC design and SC configuration can affect the organizational and financial performance of a firm [60, 76]. From a traditional research perspective, SCM aims at increasing the cost efficiency or improving non-financial factors such as product and process quality or flexibility [30, 31]. From a financial perspective, this falls short because capital lockup or the time value of money remain unconsidered [22, 23]. Despite a strong heterogeneity of the term "value" in context to SCM [27], the link between SCM and company value is conceptualized by frameworks [19, 34, 89] and quantified by formal models [8, 33, 35, 36]. Such value-based approaches are highly relevant and important in SC design and SC configuration, because in these areas SC performance measures need to address more comprehensive objectives and integrate financial factors that go beyond a mere cost or profitability focus [54, 56].

A case study from the FMCG industry is chosen (1) to empirically evaluate the coherence of SC configuration decisions under consideration of dynamics and uncertainties and resulting SC performance outcomes and value impacts and (2) to illustrate the application of the DES model for related decision support. FMCGs are products which at high turnover and comparably low cost, can act as substantial profit contributors, e.g., cosmetics, batteries, household goods, toiletries, or paper products [64]. The SC complexity in the FMCG industry is characterized by a large number of facilities [75, 77] and the resulting flows of information and material [25, 70] through inter-organizational and international networks comprising suppliers, manufacturers, distributors, retailers and service providers [32, 44, 57, 59]. Product availability is crucial in FMCG industries since consumers have limited tolerability for out-of-stock (OOS) situations and hence most likely switch to substitute products which in turn influences repurchase rates and revenues negatively [21, 32, 53]. Due to the fact that the FMCG industry features short PLCs as well as dynamics and uncertainties in the SC [71, 88], this sector is an adequate field of application. Proliferating product assortments of FMCG manufacturers result in shorter PLCs and increasing product introduction rates [24, 62].

Fig. 1 Demand patterns of volume commitments considering pipeline filling over the projected PLC [72]
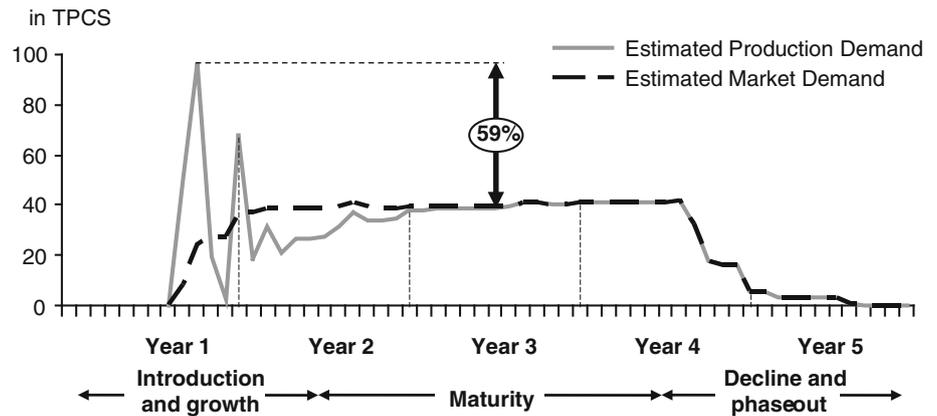
Furthermore, demand uncertainties are of great relevance for FMCG manufacturers because they affect product availability, inventory levels and the effective use of assets [1]. Additionally, PLCs in the FMCG industry show strong dynamics that are caused by uncertain overall product demands, pipeline filling requirements during product introduction and obsolete stock management during product phase-out [40, 72]. Besides, aspects of value creation are of particular interest for SCM in the FMCG industry [10, 33].

The remainder of this paper is structured as follows. The next section comprises a brief review of related literature. A conceptual framework for value-based SCM is described in Sect. 3. In Sect. 4, the case study is verbally described and methodological issues are addressed. The simulation model is introduced in Sect. 5. The subsequent Sect. 6 comprises the numerical results and their interpretation. The paper ends with a discussion in Sect. 7 and concluding remarks on findings, limitations and further research opportunities in Sect. 8. In the 'Appendix' of the paper, problem data are given to enable future research.

2 Literature review

2.1 Supply chain configuration and new product introduction

The areas of SC configuration and NPI have received considerable attention in scientific research. Comprehensive literature reviews on SC design and configuration are given by Meixell and Gargeya [54] or Melo et al. [56]. The authors observe that most related models are limited to cost efficiency or profit maximization, although capital-related factors such as fixed assets and inventory or other financial aspects strongly influence the configuration of a global SC. Hence, related SC models should encompass more performance criteria. Furthermore, multi-tier SC comprising

internal production sites and external suppliers need to be taken into account. The need to integrate SCM decision-making and new product development is emphasized in various research papers [14, 15, 61, 62]. Hence, the brief literature review presented here focuses on SC configuration for NPI.

In many cases, SC configuration for new products is considered an optimization problem. Chauhan et al. [17] introduce a mixed integer programing (MIP) model to configure the SC for a new product thereby minimizing total costs. Graves and Willems [29] apply a dynamic programing model for SC configuration to minimize total SC costs comprising inventory holding cost, transport cost up to the customer, and cost of goods sold (COGS) in NPI. Butler et al. [13] present a robust MIP model that maximizes net profit while considering the complete PLC and demand uncertainties. Wang and Shu [86] propose a configuration model based on fuzzy sets to reflect and evaluate SC uncertainties. The objective of the model is to minimize total SC costs, while maximizing the possibility to achieve the target fill rate.

Higuchi and Troutt [40] apply a system dynamics simulation approach to analyze SC dynamics arising from demand variability at the example of a short life cycle product from the consumer electronics industry. The authors observe re-amplifying bullwhip effects and show that early setting of product and SC specifications is important, because it is hardly possible to achieve improvements later on.

2.2 Value-based supply chain management

Existing literature indicates that value-based SCM has been of great interest for academic research for more than a decade. Based on a review of related conceptual papers, Francis et al. [27] observe a strong terminological heterogeneity in the related field of research. Hahn and Kuhn [34] present a review of quantitative models for value-based

SCM and propose a framework for model-driven and value-oriented decision support systems. A comprehensive review of empirical research on financial performance outcomes of SCM is given by Shi and Yu [76]. Based on selected papers, a brief outline of conceptual, model-based and empirical research is presented here.

The conceptual aspects are among others considered by Christopher and Ryals [19] who assess the framework of VBM and shareholder value and its links to SCM. The authors identify sales, cost, and capital to be the levers of SCM that drive shareholder value by enhancing or accelerating cash flows through internal processes as well as interfaces to customers and suppliers. Lambert and Burduroglu [48] evaluate the impact of logistics on these levers and propose a framework to measure the resulting value contribution. Shareholder value is identified as the most comprehensive measure to quantify logistics impact on company value. Moreover, the need for cost effective ways to measure this impact is addressed. Lambert and Pohlen [49] introduce metrics for eight SC processes and their link to corporate performance and propose a framework to translate SC performance into shareholder value. Hofmann and Locker [43] conceptualize how SCM affects shareholder value and suggest a value-based performance measurement system to link operating SC activities to economic value added (EVA). The performance measurement system is tested in a single case study from the packaging industry.

Quantitative approaches for value-based SCM can be differentiated between purely value-based approaches and hybrid value- and volume-based concepts. Brandenburg and Seuring [9] employ discounted cash flows (DCF) in a value-based model to measure and compare value impacts arising from changes of working capital and SC cost. Timing and continuity of value driver developments are found to be crucial for the overall value creation. A hybrid value- and volume-based optimization model that combines financial and physical flows in an SC is proposed by Hahn and Kuhn [33]. A robust optimization method for value-based performance and risk management in SCM is suggested and illustrated at a case example from the consumer goods industry by Hahn and Kuhn [36]. In another paper, Hahn and Kuhn [35] propose a holistic framework for value-based SC planning and present a tactical SC sales and operational planning model to optimize sales, operations and financial decisions for shareholder value creation by maximized EVA.

Empirical aspects of value-based SCM are assessed thoroughly by Hendricks and Singhal [38, 39] in event studies of 519 and 827 SC disruptions, respectively, and their impacts on stock price. Production and delivery delays are found to have a negative influence on the stock price of a firm. Losbichler and Rothböck [51] analyze the development of working capital and its components in a study among 6,925 European companies between 1995 and 2004. One major observation is that working capital has been moved upstream within European SCs with original equipment manufacturers (OEM), apparently optimizing their working capital at their suppliers' expense. In a secondary data analysis of ten leading FMCG manufacturers, Brandenburg and Seuring [10] evaluate the impacts of working capital and SC cost on company value. Focused on these value drivers, all companies create value through SCM with monetary working capital components having a considerable relevance for value creation.

2.3 Supply chain management in the fast-moving consumer goods industry

The FMCG industry is of particular interest for academic research in SCM, as illustrated by van Hoek and Chapman [41, 42] at different examples of NPI for the fashion, consumer goods and consumer electronics industries. Especially, the effects of dynamics and uncertainties in FMCG SCs are discussed in several papers. Tahmassebi [83] considers control and management of multiple plants in a multilevel distribution system from the FMCG industry. A stochastic model is suggested to evaluate alternatives for strategic redesign and operation of an existing SC at uncertain demand situations. Kellner et al. [45] employ an optimization model to assess the robustness of a reconfigured distribution network for FMCGs. Reiner and Trcka [67] propose a simulation environment to evaluate SC design alternatives under consideration of demand uncertainties. Based on a case study from the food industry, the authors observe that general statements like "short SCs reduce bullwhip effects" or "the utilization of point of sale (POS) data improves a manufacturer's planning situation" are not always valid and emphasize the need to consider the characteristics of the specific SC.

In a longitudinal SC study of toy manufacturers and retailers, Wong et al. [88] assess SCM practices for dealing with unpredictable and variable demand and reveal mismatches between manufacturers and retailers. Seasonality, customer requirements, short PLCs and selling windows as well as a substantial proportion of new products and promotional campaigns are identified as main causes of demand fluctuations.

Impacts of SCM on company value in the FMCG industry are evaluated by Brandenburg and Seuring [10] in a secondary data analysis of ten leading FMCG manufacturers. It is observed that all companies created value by reducing working capital or SC cost and that monetary working capital components are of considerable relevance for value creation.

Table 1 Related literature

Paper	SNP	NPI	VBM	FMCG	Dynamics	Uncertain	Method
Hoek and Chapman [41]		x		x		x	Conceptual
Hoek and Chapman [42]		x		x		x	Case study
Tahmassebi [83]	x			x	x	x	Simulation
Kellner et al. [45]	x			x	x	x	Optimization
Reiner and Trcka [67]	x			x		x	Simulation
Wong et al. [88]				x	x	x	Case study
Brandenburg and Seuring [10]			x	x			2nd data
Chauhan et al. [17]	x	x					Optimization
Graves and Willems [29]	x	x				x	Optimization
Butler et al. [13]	x	x				x	Optimization
Wang and Shu [86]	x	x				x	Optimization
Higuchi and Troutt [40]	x	x			x	x	Simulation
Christopher and Ryals [19]			x				Conceptual
Lambert and Burduroglu [48]			x				Conceptual
Lambert and Pohlen [49]			x				Conceptual
Hofmann and Locker [43]			x				Conceptual and case study
Brandenburg and Seuring [9]			x				Quant. model
Hahn and Kuhn [33]			x				Optimization
Hahn and Kuhn [35]			x			x	Optimization
Hahn and Kuhn [36]			x			x	Optimization
Hahn and Kuhn [34]						x	Conceptual and lit. rev.
Hendricks and Singhal [38]			x				2nd data
Hendricks and Singhal [39]			x				2nd data
Losbichler and Rothböck [51]			x				2nd data

2.4 Summarized observations

Recent developments and findings of related research are briefly summarized in order to outline the motivation of this paper. Table 1 illustrates the following three observations of the literature review:

1. SC configuration is of particular interest for scientific research and industrial practice.
2. SC configuration decisions should be made under consideration of dynamics and uncertainties. Furthermore, the whole PLC should be taken into account thereby improving the integration of SCM and NPI processes.
3. SC configuration decisions should not be limited to profitability aspects. Instead, non-financial SC performance factors and ultimately aspects of financial value creation need to be considered in such decisions.

The motivation of the paper at hand is to develop SC configuration decisions further from a traditional SC performance evaluation to a value-based assessment. Therefore, a conceptual framework for value-based SCM is outlined in Sect. 3. The relevance of this development and the suitability of simulation models for related decision

support is illustrated at a case study from the FMCG industry. The paper contributes to research on the coherence of SCM and value creation as well as on the integration of SCM and NPI processes.

3 Conceptual framework for value-based supply chain management

The influences of SC configuration decisions, uncertainties, and dynamics on company value are elaborated in a theorizing desk research [37]. Conceptual elements are identified and combined to a framework for value-based SCM to which SC configuration and its complexity drivers dynamics and uncertainties are linked.

The financial performance of a firm is influenced by SC-related impacts on the value drivers sales, cost, and working capital and fixed assets [19]. Main components of SC costs (see papers in [74]) are transportation cost, inventory holding cost and COGS. The latter reflects the direct costs and overheads associated with the physical production of products for sale [63]. Fixed asset aspects are considered through investments in machinery and equipment (see e.g., [35]), which are required in case a (production) technology

Fig. 2 Complexity drivers and value drivers in a framework for value-based SCM
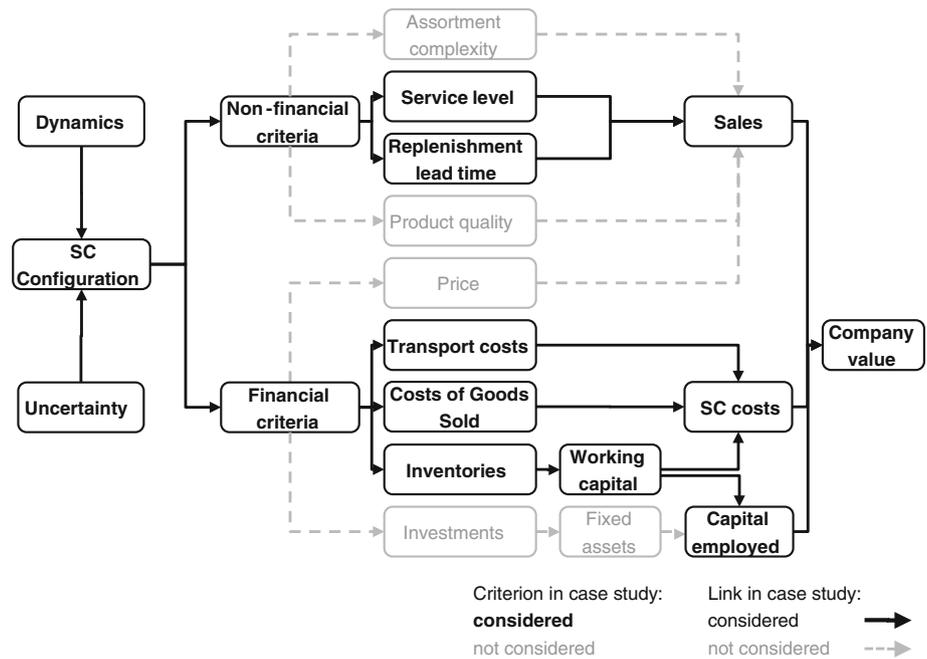
is newly allocated to a production site, established for the first time in a production network, or if an extension of existing capacities is required. Moreover, the depreciation of the investments also needs to be reflected in product costs and therefore SC costs. Working capital aspects are taken into account by inventories comprising cycle, safety and transit stocks of components and finished goods [9, 65].

Non-financial performance criteria include service level [30], SC flexibility and reactivity [3], product range and assortment complexity [12, 24, 31], and product quality [31]. These operational performance aspects again strongly influence the financial situation of a company [66]. Service level, in particular ready rate or fixed rate, measures the degree of product availability which in turn directly affects the initial purchase and repurchase rate of a product and hence the revenue of a company [53]. Furthermore, brand manufacturers face the challenge to reduce replenishment lead times (RLTs) [16], which indicates the flexibility and responsiveness of an SC [31] and again influences the sales of a company [18].

The complexity drivers uncertainties and dynamics influence SC configuration decisions which in turn affect company value itself by financial as well as non-financial performance criteria [30]. These interdependencies are outlined in a framework for value-based SCM as illustrated in Fig. 2. Based on this framework, performance criteria are selected to evaluate candidate SC options in the case study presented in this paper.

In SC configuration for the FMCG industry, these performance criteria are either considered in a static way, if the criterion is to a large extent independent of dynamics or

uncertainties, or in a dynamic way, if dynamics and uncertainties have a strong influence on the performance criterion. The financial evaluation of cost and investments is largely independent of dynamics or uncertainties. Therefore, these factors can be estimated in a static approach for each considered SC option. In contrast, working capital requirements are strongly influenced by dynamics and uncertainties [7] and hence must be measured dynamically. Similarly, non-financial criteria are subject to significant impacts of dynamics and uncertainties and can only be calculated analytically if the system is assumed to be in a steady state with stationary demands (see e.g., [13, 20]). These non-financial performance criteria comprise service level, measuring product availability, and RLT, a driver of the flexibility and reactivity of an SC. Product price and quality, being an order qualifier for market entry, and assortment complexity, which is rather driven by assortment strategy than by SC design decisions, are not considered as decision parameters for SC configuration.

4 Case study

4.1 Case study research process

To ensure the required scientific rigor of this case study [73], the case study research process suggested by Stuart et al. [82] is employed. The process step "instrument development" is executed by designing a DES model as described in Sect. 5. The execution of the process steps

Fig. 3 Candidate SC options

● Bubble size represents demand volume
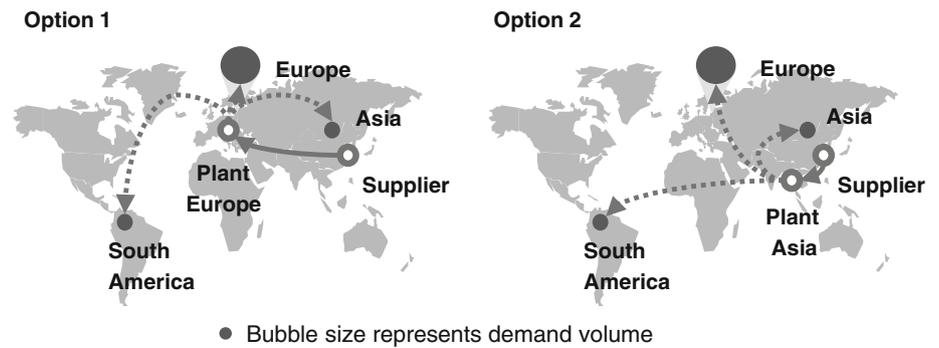
"data gathering" and "data analysis" is described in Sect. 6. Discussion and conclusion presented in Sects. 7 and 8 represent the process step "dissemination".

4.2 Case description

The case example builds on a realistic NPI project from a global FMCG manufacturer introduced by Schilling et al. [72]. It comprises one cosmetics product line with three language variants (stock keeping units, SKU), one for each demand region Europe, covering the majority of the demand, Latin America and Asia. Country-specific launch dates are reflected in the regions' demand patterns based on sales volume commitments for the whole PLC which are collected from local affiliates during the NPI project several months prior to a launch.

The two candidate SC options comprise three echelons with a supplier located in Asia, production centers in Europe (SC option 1) and Asia (SC option 2), and DC in each of the three demand regions (see Fig. 3). For the supplier, restrictions regarding a fixed order quantity and a daily production capacity apply. Moreover, supplier capacity is only available from a certain point in time on with a capacity ramp-up phase at reduced capacity. In the plants, setup activities and production cycles are reflected by a (technically derived) fixed production quantity and a fixed production lead time of one week. The SC operates under a make-to-stock policy based on forecasted demands. The market demand, e.g., from wholesalers, distributors or retailers, is satisfied directly from a DC's stock in a monthly cycle. In case the complete demand cannot be fulfilled, backorders are not allowed and result in lost sales. The transport times in the SC network vary between seven days for distribution within one demand region and up to eight weeks for intercontinental shipments.

5 Simulation model

Due to the structure of the considered case study, a DES model [47] is chosen for this evaluation. Simulation techniques help understanding causalities in SC performance [75] and permit evaluating a system's operating performance prior to its implementation [16], especially since variability of parameters (uncertainties) and interplays over time (dynamics) can be reflected [40]. A comprehensive introduction of simulation methods is given by Biswas and Narahari [5], Terzi and Cavalieri [84] or Kleijnen [47].

The model of the SC is built with the DES software ARENA[TM] from Rockwell Automation [68] and has been validated by internal cross-checks and extensive analysis. Since the evaluation of the ramp-up phase of the SC options is of special interest, a terminating simulation and analysis approach is used [46].

The simulation model reflects three echelons of the SC: the packaging supplier, the production plants and the demand regions. The model can be adapted to the each considered SC option, i.e. the product allocation decision, by adjusting the problem parameters (see Table 2).

The make-to-stock policy is incorporated through a dynamic (r, S_t) inventory policy in the DCs for finished goods and plants for packaging materials. In a monthly ordering cycle $(r = 1)$ inventory orders x_t are placed at the preceding echelon, i.e. plant or supplier, so that the order-up-to level S_t would be reached if the order was delivered at once:

Table 2 Overview of parameters and symbols

Parameter	Description
r	Review period
t	Time period
S_t	Target order-up-to level in period t
SS_t	Safety stock in period t
i_t	On-hand inventory in period t
j_t	On-order inventory in period t
x_t	Inventory order in period t
y_t	Mean forecast demand in period t
$\sigma(y_t)$	Standard deviation of forecast demand in period t
lt_{sd}	Lead time from origin s to destination d
z	Normal distribution safety factor

$$x_t = S_t - (i_t + j_t). \tag{1}$$

The dynamic order-up-to level S_t in each period t is then calculated based on forecast demands assuming a risk period of $(1 + ltsd)$ time periods:

$$S_t = SS_t + \sum_{i=t}^{t+ltsd} y_i. \tag{2}$$

The safety stock level (SS_t) per SKU in each period t is calculated based on a normal distribution safety factor z assuming a ready rate of 95 % [78]:

$$SS_t = z \cdot \sqrt{\sum_{i=t}^{t+ltsd} \sigma^2(y_t)}. \tag{3}$$

Note: Eq. (3) assumes that backorders are allowed while unfulfilled demands in the considered case study result in lost sales. However, Eq. (3) is chosen as an appropriate proxy for safety stock calculation, because service level requirements are very high in the considered case study (see [4] for a comprehensive review of lost sales inventory theory and [26] for a numerical analysis of safety stock calculation formulas).

Variations of standard deviations over time, which can occur especially during the ramp-up phase of the PLC, could be estimated empirically based on more established products of the assortment [78]. However, for simplicity reasons, identical values are assumed for all periods. Nevertheless, in the ramp-up phase, mean demand was assumed to be lower than in the stationary phase: Thus, assuming identical standard deviation for all periods the coefficient of variation results to appropriate values reflecting the higher demand variability during the ramp-up phase.

Uncertainties in the demand signal are modeled by distinguishing between the level of expectation value, representing over- and under-estimation of market demand (contingency planning), and the variance, describing the random fluctuation in demand. The random fluctuations are assumed to be normally distributed at specified forecast accuracy, while contingency planning is calculated with a scenario-specific factor. In the latter case, the demand forecasts are also allowed to be adjusted automatically by the system after an assumed "learning period" of three months. This reflects the potential of an organization to comprehend the overall market acceptance of a particular product. Pipeline filling demand volumes prior to product launch dates are assumed to be deterministic as retailers initially need to fill up all shelf facings and stocks.

The value contribution of a SC option is measured using the net present value (NPV) of SC-related DCFs. Due to dynamics and differences in SC configuration, different SC options require cash expenditures or generate payments at different points in time. To measure the value contribution of cash flows related to the SC only and exclude marketing and sales effects like pricing or media investments, the revenue is calculated based on a transfer price (tp) which is paid by the sales division in the market to the SC organization. Incoming payments (ci_t) result from successful deliveries to a customer, i.e. the demand quantity (d_t) that is not lost (ls_t):

$$ci_t = (d_t - ls_t) \cdot tp. \tag{4}$$

Cash expenditures (co_t) are assumed to be incurred at the time t of consumption, i.e. when packaging material (quantity p_t purchased at cost pc) is delivered or finished goods (quantity q_t) are produced and shipped. The calculation formula reflects that total production costs (tc) comprise non-cash items (ncc) such as depreciation and that the time of finished goods production and packaging supply diverge:

$$co_t = p_t \cdot pc + q_t \cdot (tc - ncc - pc). \tag{5}$$

The net cash flow cf_t per period t is then calculated directly as the difference of cash-in ci_t and cash-out co_t:

$$cf_t = ci_t - co_t. \tag{6}$$

For a horizon of T monthly time buckets and for annual capital cost w, the expected NPV V is calculated by applying the DCF method [11]:

$$V = \sum_{t=0}^{T} \frac{cf_t}{\left(1 + \frac{w}{12}\right)^t}. \tag{7}$$

6 Data analysis and results

6.1 Data gathering

For confidentiality reasons, the collected data and structures, in particular cost information, have been adapted without loss of academic relevance of problem structure and characteristics. Various validation and verification procedures of both model and output are performed [46, 52]. The model is validated by internal cross-checks using dynamic counters as well as thorough observation of process animations. The created demand patterns and model results are validated by comparison with historical data.

Based on the two components of demand uncertainties, short-term forecast accuracy and long-term contingency planning, several scenarios are defined arbitrarily to conduct a structured analysis of SC complexity drivers' impacts. The results presented in Sect. 6.2 show the monthly average values over a number of 158 replications with random demand variations which is found to be sufficient to produce results with an error of <5 % at a 95 %

Table 3 Overview of scenario settings

Scenario	Demand pattern	Short-term forecast accuracy (%)	Long-term contingency planning (%)
1	Launch pattern and pipeline filling	100	–
2		93	–
3		85	–
4		78	–
5		70	–
6		63	–
7		55	–
8	Launch pattern and pipeline filling	85	+30
9		85	+20
10		85	+10
11		85	–
12		85	−10
13		85	−20
14		85	−30
15		85	−40
16		85	−50

Scenario 3 and 11 are identical

confidence interval on total inventory values and order lead times. Scenarios 1–7 analyze SC performance under increasing short-term demand variability, while scenarios 8 to 16 provide insight into the effects of a long-term over- or underestimation of product reception in the market (see Table 3).

6.2 Numerical results

Differences between both candidate SC options and impacts from uncertainties and dynamics on SC performance are evaluated in detail for each performance criterion: cost and investments, service level, capital lockup resulting from inventory, and flexibility measured by RLT. Furthermore, the value impacts and potential risks of each SC options are compared.

Costs and investments Estimated landed costs—comprising transport cost and COGS—for all three SKUs as well as packaging materials have been calculated per SC option based on production and transport cost information. Due to lower production costs, SC option 2 yields 2 % lower landed costs per SKU than SC option 1. In each considered plant, the available production equipment meets the technical requirements for manufacturing. As a consequence, fixed asset investments were not required in any considered SC option. These performance factors indicate advantages for SC option 2.

Service level The simulation results indicate that each SC option is able to achieve an adequate service level and

Table 4 Service level comparison

	Ready rate			Fill rate		
	Europe (%)	Latin America (%)	Asia (%)	Europe (%)	Latin America (%)	Asia (%)
Option 1						
Min	88.9	88.1	87.6	93.9	92.3	91.1
Max	99.8	100.0	99.9	100.0	100.0	100.0
Avg	95.9	97.3	96.1	98.3	98.2	97.6
Std	2.3	2.5	2.7	1.3	1.7	1.9
Option 2						
Min	82.8	87.4	90.8	92.7	92.2	92.7
Max	98.9	100.0	99.6	99.8	100.0	99.7
Avg	92.7	97.4	97.3	97.4	98.5	97.9
Std	3.1	2.6	1.9	1.4	1.6	1.4

The table shows ranges of ready rate and fill rate per demand region and per SC option. These results were obtained from 158 replications for each SC option and each demand scenario.

to support the desired launch schedule (see Table 4). Both candidate SC options are capable of supplying each demand region with a desired average fill rate of at least 95 %. Considerable differences between both SC options were not observed, although SC option 2 shows an average ready rate in the European demand region that slightly falls behind the expectation. Accordingly, SC option 1 shows slightly higher average fill rates in Europe, but SC option 2 achieves higher average fill rates in Asia and Latin America. As indicated by the standard deviations of the fill rate, the responsiveness of each SC option seems to be sufficient to cope even with major underestimations of the market reception.

Capital lockup The inventory level of each SC option follows similar demand-driven developments in general, with SC option 2 showing a higher peak in finished goods' inventories during pipeline filling activities. Considerable transport time differences from the two candidate plants to the European markets drive inventory value levels. Due to longer transport time from the plant to Europe in SC option 2, pipeline filling inventories remain in the SC much longer and more capital is bound over a longer time. Figure 4 illustrates the differences in the inventory value profiles. On average, the total inventory value of all stocks is about 25 % higher over the whole PLC in SC option 2 than SC option 1. Hence, the simulation results indicate a considerable advantage of SC option 1 with regard to capital lockup.

A more detailed analysis of the numerical results reveals some interesting insights. Although transport times between production plant and supplier are longer in SC option 1, packaging goods inventory levels on average do

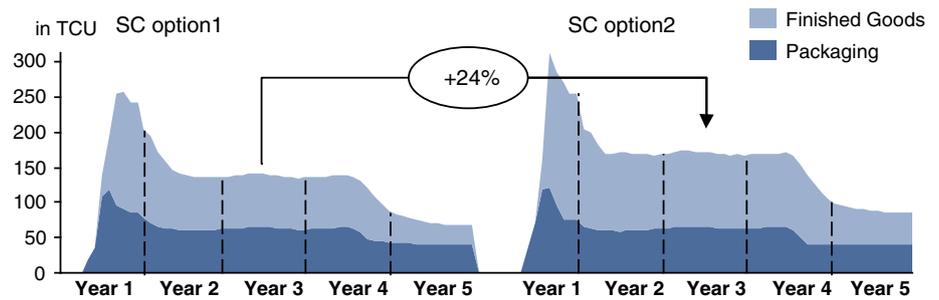**Fig. 4** Average inventory value profiles for both SC options (scenario 3)

Fig. 5 Impacts of short-term demand uncertainties on average inventory value profiles
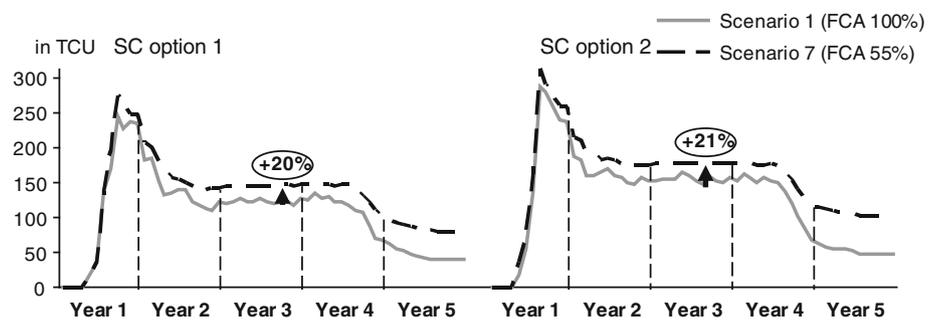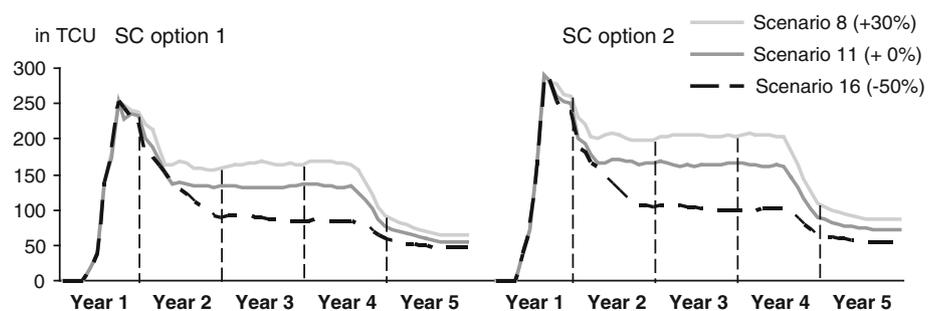

Fig. 6 Impacts of long-term demand uncertainties on average inventory value profiles

not differ strongly (on average between 2 and 4 %). Moreover, it is observed that increasing short-term demand uncertainties lead to higher average inventory levels in both SC options (see Fig. 5). A major proportion of the inventory growth is caused by increasing safety stocks due to decreasing forecast accuracy.

Furthermore, a positive correlation between long-term contingency scenario and inventory level is observed in each SC option, as illustrated in Fig. 6. This effect is based on the assumed "learning system" which is able to adjust the inventory levels to the observed market reception within a comparably short time. Nevertheless, on average the total inventory value of SC option 2 is about 25 % higher than the stock value of SC option 1.

It is to mention that the inventory levels in this model are determined based on a static demand deviation which represents a simplifying assumption. Stößlein et al. [81] detected empirically that safety stocks, which account for about 20 % of all inventory, can be reduced by about 5 % in the FMCG industry when dynamic deviations are taken

into account. As a consequence, the inventory levels in this study show an inaccuracy of about 1 %. Nevertheless, the overall conclusions drawn from the numerical analysis presented in this paper remain valid.

Flexibility With regards to RLT, thus SC flexibility, the results indicate that SC option 1 is able to react considerably faster to unforeseen demand changes than SC option 2. The RLT of finished goods to Europe reacts quite sensitively to the packaging material bottleneck in SC option 1, but at the beginning of the PLC, the total lead time, i.e. from supplier to Europe, is much shorter than in SC option 2. This effect can be explained by the fact that the longer lead time from the Asian plant to Europe (SC option 2) requires significantly higher packaging material volumes to be ordered earlier, mainly during capacity ramp-up.

The simulation results are analyzed in greater detail with regard to RLT for finished products and for packaging material. Differences in finished product RLT from the plants to the markets are found as expected between SC option 1 and SC option 2, since processing and transport

times are considered static. A considerable difference is recorded in finished product RLT from the plants to Europe. While SC option 1 is able to deliver within 2–3 weeks, SC option 2 requires 7–8 weeks. However, at the beginning of the PLC, finished product RLT to Europe double in SC option 1 as the supplier ramp-up bottleneck is carried forward and the production orders have to wait for packaging material supply at the plant (see Fig. 7).

In the maturity stage of the PLC, the RLT for packaging materials in SC option 2 is approximately 33 % shorter than in SC option 1. However, internal SC dynamics created by a combination of a supplier ramp-up phase, pipeline filling requirements, and country-specific launch patterns lead to a supplier capacity bottleneck prior to the crucial product introduction phase. As a result, the packaging material RLT in SC option 2 increases at the beginning of the PLC during supplier capacity ramp-up and even exceeds the packaging material RLT of SC option 1 (see Fig. 7).

Value creation On average, the NPV created by SC option 1 is about 70 % higher than the value contribution obtained by SC option 2. This advantage of SC option 1 increases by growing uncertainty. At decreasing forecast accuracy and increasing misestimation of overall market developments, the NPV obtained by SC option 1 outperforms the value contribution of SC option 2 by more than 80 %. As a consequence, SC option 2 has considerably longer payback periods (on average nearly 50 % longer), as illustrated in Fig. 8.

Risk From a project planning and risk management perspective, the findings indicate that SC option 2 is likely to react more sensitively to project schedule delays than SC

option 1. In case of a delay, costly expediting actions such as a switch of the transport mode from ocean shipping to airfreight, would be required to hold launch timing while impairing the cost advantage of SC option 2. Beyond this, the shorter payback period of SC option 1 indicates its advantage to reduce the risks that arise from long-term changes of competitor and customer markets.

Summarized comparison Table 5 summarizes the results from the dynamic evaluation of both candidate SC options. The results indicate that at comparable fill rates, SC option 1 utilizes 20 % less inventory than SC option 2. Furthermore, SC option 1 offers a higher responsiveness due to considerably shorter RLT to the main market Europe, especially during the product launch phase. Additionally, the simulation runs provide evidence that SC option 2 might react quite sensitively to delays. A structured analysis of influences from demand and market uncertainties suggests that SC option 1 is able to maintain its performance advantages even if these influences apply. However, at the same time accumulated landed costs in SC option 2 are approximately 2 % lower than in SC option 1.

While a mere cost comparison would favor SC option 2, the non-financial evaluation suggests SC option 1 to yield better overall SC performance. As a consequence, a clear decision for the one or the other SC option is only possible if financial and non-financial criteria are either clearly prioritized or integrated into one measure. By linking volume-based simulation results and financial information in the value-based SCM framework, SC designs can be assessed based on their value contribution. The comparison of NPV figures and payback periods show that SC option 1

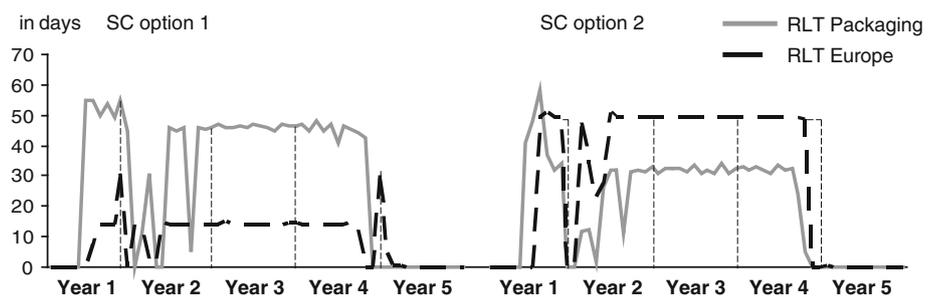**Fig. 7** Impacts of dynamics on average replenishment lead times (scenario 1)
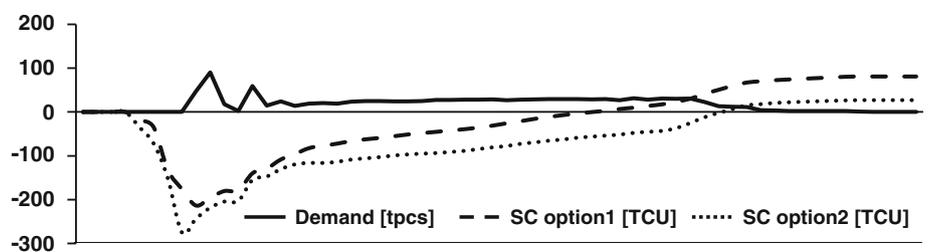
Fig. 8 Demand profile and NPV developments of both SC options

Table 5 Summary of evaluation results

Criterion	SC option 1 (plant Europe)	SC option 2 (plant Asia)
Cost		−2 % versus SC option 1
Investments	No investment required	
Inventory		+25 % versus SC option 1
Service level	Similar results in both SC options	
Flexibility (RLT)	Higher flexibility	
	Shorter average RLT of packaging materials during product introduction	Shorter average RLT of packaging materials to plant during maturity stage
	Significantly shorter average RLT from plant to Europe	
	Shorter total RLT from supplier to main market during product introduction phase	
Value	Higher NPV (+69.9 %)	Longer payback period (+48.5 %)
Risk	Advantage to mitigate risks of long-term market changes	Expected to react more sensibly to project timing delays, requiring costly expediting actions

results in stronger value contributions. Hence, SC option 1 would be recommended from a value-based perspective.

7 Discussion

The simulation results of this case study illustrate that capital-related value drivers have to be taken into account in the assessment of SC configuration options even if fixed asset investments are not needed. As a consequence, it has become clear that a pure focus on cost efficiency falls short when optimizing the overall value contribution of a SC configuration. These observations illustrate the need to integrate value-based factors into SCM, as suggested by Melo et al. [56] or Meixell and Gargeya [54]. From the methodological point of view, simulation is proven as a powerful tool to assess the performance of a SC in a financial or value-based way that can complement normative models, e.g., the ones suggested by Hahn and Kuhn [33, 35, 36].

The presented approach to value-based SCM is in line with the framework introduced by Christopher and Ryals [19] that comprise sales, cost and capital and with the metrics for the NPI process according to Lambert and Pohlen [49]. While Lambert and Burduroglu [48] focus on value contributions arising from logistics only, this paper considers international and cross-functional SC aspects of value creation. In contrast to Schilling et al. [72], who limit the assessment of SC configuration options to costs and non-financial SC performance factors, the paper at hand reflects aspects of financial value creation. This case study and the simulation results provide empirical support for the statement that delays in an SC have a negative impact on company value, as observed by Hendricks and Singhal [38, 39]. Furthermore, this case study shows that cost and inventory are considerable value drivers in the FMCG industry, as pointed out by Brandenburg and Seuring [9].

Additionally, the applied simulation approach adds to hybrid value- and volume-based quantitative methods in value-based SCM, as suggested by Hahn and Kuhn [33, 36].

In contrast to other quantitative approaches that apply optimization techniques to SC configuration problems in NPI [17, 29], DES is employed in this case example. While optimization approaches are able to consider demand uncertainties [13, 86], their ability to cope with dynamics is limited. Similar to Higuchi and Troutt [40], the simulation model presented in the paper at hand considers dynamics and uncertainties simultaneously and addresses the problem arising from introducing products with short PLCs and high product availability requirements. In contrast to the paper at hand, Higuchi and Troutt [40] limit the assessment to a selective and isolated evaluation of SC performance criteria. In the case example assessed by Higuchi and Troutt [40], dynamics are caused externally by shadow demands which occur due to a significant under-estimation of a product's market reception. Pipeline filling activities are intended to mitigate this effect, but on the other hand create internal dynamics in the SC as shown in this paper.

Although other papers discuss the relevance of uncertainties (see [6, 13, 87]) and dynamics (see e.g., [85]), the contribution of this paper is to consider both complexity drivers in a combined value-based and volume-based evaluation. Additionally, the illustration and discussion of pipeline filling aspects enriches the current research on NPI as well as the consideration of such self-created SC dynamics in SC planning.

8 Conclusion

This paper analyzes the performance drivers of an SC configuration over the whole PLC. A conceptual

framework for value-based SCM is proposed which links the SC complexity drivers dynamics and uncertainties to SC-related drivers of company value. Beyond this, the performance outcomes and value impacts of SC configuration decisions are evaluated by simulation in case study from the FMCG industry, taking into account the specific requirements of the PLC, especially before and during product launch. The simulation study illustrates the impacts of both non-financial and financial criteria of SC performance on company value.

Limitations of the proposed framework for value-based SCM arise from the fact that links between SCM and other aspects of VBM, e.g., the impact of SC risk on weighted average cost of capital, are not considered. Furthermore, this framework is not related to various aspects of strategic and operational SCM. A limitation of the simulation model is that processing durations for transportation and production are assumed static. As a consequence, the RLT is independent of uncertainties. Furthermore, the standard deviation of demand is assumed static over time and as a consequence, the determined safety stock levels are slightly imprecise (see [81] for a related empirical analysis). Moreover, expediting actions are not considered. Thus, cost aspects arising from project delays cannot be evaluated.

Further research is suggested on operational, tactical and strategic level. On operational level, different aspects of pipeline filling, e.g., its impact from self-induced demand peaks on production planning can be studied. On tactical level, the modeling and analysis approach can be extended to reduce time to market or evaluate flop scenarios. Furthermore, SC-related impacts of marketing decisions during NPI, e.g., regional launch postponements to react to global supply bottlenecks, can be evaluated. Beyond this, the application of normative models is encouraged, e.g., to assess trade-offs between cost reduction, service level optimization and NPV maximization in greater detail. To enable related research, problem data are presented in the 'Appendix' of the paper. The DES model which is presented in this paper can be employed to support strategic decision-making for SC design. Moreover, additional research is suggested on whether and how these FMCG-specific issues need to be incorporated as frame conditions into strategic SC design problems for the FMCG industry. Some elements of the conceptual framework for value-based SCM, e.g., price effects on sales or fixed assets, are not considered in this paper. With regard to SC performance outcomes, this paper illustrates the relevance of integrating the financial value perspective into SCM and encourages further related research.

Appendix: Problem parameters

Due to confidentiality reasons, it is not possible to disclose financial and demand data that was used for the numerical analysis of the case study. In order to enable further research, realistic ranges of problem parameters are presented that can be used to generate suitable problem instances without loss of academic relevance.

Network structure data

The considered supply network comprises three echelons.

- A packaging supplier S delivers packaging material to production plants P1 and P2.
- The new products could be allocated to two candidate production plants P1 and P2 that globally supply the demand regions.
- The global demand is separated into the tree demand regions (R1, R2, R3), each comprising up to four demand markets (M1.1, ..., M3.4).

Demand data

Demand data inform about the global market potential and its spatial and temporal distribution. An example is given in Table 6.

- In each demand market (M1.1, ..., M3.4), the market-specific PLC length is 36 months that are grouped into three years (Y1, Y2, Y3).
- The product launch date depends on the specific demand market. Over all demand markets, the launch dates can vary by up to 12 months. As a consequence, the PLC length is four years on a global level.
- The expected global market potential over the whole PLC is 1.5 million pieces, and the actual global market potential can be up to 50 % higher or lower.
- Demand region R1 represents 75 % of the global market potential, the remaining market potential is equally distributed over the other two regions R2 and R3. Each demand market M1.1, ..., M3.4 represents on average 10 % and at most 35 % of the global market potential.
- Due to pipeline filling requirements, the average monthly demand in Y2 is up to 60 % lower than the peak quantity that is needed when the product is launched in the marketplace.

Table 6 Market-specific launch timing and annual demand quantities

Demand region	Demand market	Launch month	Annual demand		
			Y1	Y2	Y3
R1	M1.1	0	57	59	65
	M1.2	1	195	173	178
	M1.3	4	117	120	124
	M1.4	12	8	9	10
R2	M2.1	0	45	50	55
	M2.2	11	8	12	24
R3	M3.1	2	35	27	21
	M3.2	4	5	6	6
	M3.3	6	21	26	29
	M3.4	12	4	5	6

Table 7 Transport durations (in days)

From	To					
	Production plant		Demand market			
	P1	P2	R1	R2	R3	
S	42	28	n.a.	n.a.	n.a.	
P1	n.a.	n.a.	7	42	42	
P2	n.a.	n.a.	42	7	56	

Supply data

Supply data inform about transport durations and minimum lot sizes that have to be respected. Given the fact that the considered product represents only one item of a very large product assortment, capacities for production, transportation and storage can be assumed unbounded.

- The minimum order quantity for packaging material is 30,000 pieces.
- The minimum production quantity at each of the two potential plants P1 and P2 is 30,000 pieces.
- Only full pallets can be transported. The pallet size is 6,500 pieces for packaging material and 1,800 pieces for finished goods.
- Transport durations from the packaging supplier S to each production plant as well as from each production plant to each demand region are given in Table 7.

Financial data

Financial data are given as a share of the product-related transfer price which a production center charges to a

Table 8 Cost components and transfer prices (in currency units)

Cost component		Plant P1	Plant P2
Raw and packaging material costs		0.60	0.60
Inbound logistics costs		0.03	0.02
Conversion costs		0.23	0.24
Surcharges and royalties		0.18	0.14
Outbound logistics costs	To demand region R1	0.00	0.03
Outbound logistics costs	To demand region R2	0.03	0.04
Outbound logistics costs	To demand region R3	0.03	0.00
Transfer price	To demand region R1	1.04	1.03
Transfer price	To demand region R2	1.07	1.04
Transfer price	To demand region R3	1.07	1.00

specific demand market as a transfer price for one supplied item. An example is given in Table 8.

- The transfer price depends on the production plant that supplies and the demand region that receives the product. Depending on the particular combination, the transfer prices can vary by up to 10 %.
- Raw and packaging material costs represent 60 % of the transfer price.
- Plant-specific conversion costs represent 20–25 % of the transfer price.
- Plant-specific product surcharges and royalties represent 15-20 % of the transfer price.
- Plant-specific inbound logistics costs represent up to 5 % of the transfer price.
- Outbound logistics costs represent up to 5 % of the transfer price and depend on the specific transport relation between production plant and demand region.
- The product net sales price that the manufacturer charges to the customers for one sold item is at least 2 times higher than the transfer price.
- Cost of capital can be assumed between 5 and 15 % per annum.

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