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Procurement Risk Management (PRM) at Hewlett-Packard Company

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Supply chain risks related to product demand, component cost, and availability uncertainties can have a significant impact on a manufacturing company’s revenue and profits. The Procurement Risk Management (PRM) Group at Hewlett-Packard (HP) developed and implemented a mathematical model, business process, and software to measure and manage supply chain risks on the procurement side. In 2006, the software-enabled business process helped HP to manage over $7 billion in spending; this resulted in material-cost savings of $128 million. Over the past six years, HP has realized more than $425 million in cumulative cost savings using the PRM approach.

Key words: supply chain risk management; inventory management; operations; planning; procurement; structured contracts.

Members of HP’s procurement community know that uncertainty in product demand, component cost, and component availability results in significant procurement risks. Other manufacturers, such as Ford, Cisco, and Dell, know these risks all too well. In December 2001, Ford posted a $1 billion loss on precious-metals inventory and forward-contract agreements. In April 2001, Cisco took a $2.5 billion inventory write-down due to weakening demand for networking products. In October 1999, Dell’s announcement about the revenue impact of higher-than-expected memory prices resulted in a seven percent decline in its stock price in one day.

Hi-tech components exhibit even more volatility. In Ford’s case, palladium prices doubled during 2000, and then decreased by over 50 percent in 2001. By comparison, the price of the DRAM memory that HP uses dropped by over 90 percent in 2001, and then more than tripled in early 2002 (Figure 1).

Coupled with this price volatility, there is significant uncertainty about the availability of hi-tech components including memory chips and other semiconductor products. In periods of high demand, hi-tech suppliers place original equipment manufacturers (OEMs) such as HP under allocation whereby they supply only a fraction of the OEM’s total demand. Availability uncertainty can also result from supply and delivery disruptions, such as the earthquake in Taiwan in late 1999, or supplier quality issues. In addition to component cost and availability uncertainty, manufacturers face substantial product-demand uncertainty. The dramatic drop in the demand for telecom and networking equipment in 2001–2002, after several years of breathtaking growth, is an example. Demand uncertainty has caused cycles of product and component shortages followed by inventory buildups and write-downs, e.g., Cisco’s $2.5 billion loss.

In mid 2000, HP signed a long-term, binding contract with a major supplier to actively manage the future cost and availability uncertainty of flash memory. There were significant incremental risks to HP
in entering into this forward contract. If flash memory demand weakened, then committing to buy a fixed quantity would result in significant inventory buildup and write-offs. However, if flash memory prices dropped, then HP would pay more than its competitors because of its fixed-price commitment.

This long-term, binding contract for flash memory set the course for the active management of procurement uncertainties and risks at HP. To help verify that such incremental risks due to this forward contract were acceptable and, more importantly, manageable in the future, we developed a quantitative framework—Procurement Risk Management (PRM)—to show in detail the long-term demand, cost, and availability uncertainties for flash memory, and HP’s quantity and price commitment as specified in the contract. By 2006, HP had saved an estimated $50 million using the PRM approach, as prices of memory chips increased beyond the fixed and/or capped price in the long-term contract.

Challenges: Developing and Implementing a Risk-Management Approach

HP had to overcome several technical, business process, and cultural challenges to develop and implement a risk-management system for supply chain management (SCM).

Technical Challenges in Managing Procurement Uncertainties
Current SCM practices emphasize the management of demand and availability uncertainties through inventory-buffering strategies (Graves 1988), with little, if any, focus on managing component-cost uncertainties. Financial-engineering practices, such as those used on Wall Street for stocks, bonds, and currency, enable the management of cost uncertainty; however, they do not manage demand and availability uncertainties (Hull 1993). Furthermore, such cost-uncertainty management techniques require the availability of risk-management instruments, such as call-and-put options, instruments that are not available directly for hi-tech components. For these components, such as memory and flat-panel displays, demand, cost, and availability uncertainties are equally important, and require that those uncertainties be managed together. Thus, neither existing SCM nor existing financial-engineering practices can be applied directly to the management of procurement risks of hi-tech components.

When HP initiated the PRM program in 2000, few academic papers addressed the joint management of multiperiod and correlated demand, cost, and availability uncertainties using a portfolio of contracts. Academic literature most closely related to our approach appeared after we developed our process. Martinez-de-Albeniz and Simchi-Levi (2003) developed a multiperiod framework for supply contracts with embedded quantity options under demand uncertainty; Schummer and Vohra (2003) considered the problem of a buyer procuring quantity options from multiple suppliers under demand uncertainty; and Fu et al. (2006) examined a single-period, optimal portfolio of contracts problem when both the demand and cost are uncertain. Fu et al. also presented an excellent review of the existing literature that addresses the management of demand and cost uncertainty in the supply chain.

The PRM framework that HP developed enables the simultaneous measurement and management of multiperiod and correlated demand, cost, and availability uncertainties. Existing SCM and enterprise resource planning (ERP) software does not support risk management beyond traditional inventory-buffering strategies. Therefore, to support PRM, HP developed from scratch proprietary software tools that use OR models.

Business Process Challenges
In most manufacturing companies, current SCM business processes and metrics do not support risk
management. Current SCM metrics are backward looking. For example, such metrics report actual material, inventory, and shortage costs obtained over past time periods. To enable risk management, we developed metrics that show expected values and standard deviations of future material, inventory, and shortage costs for a set of alternatives. The PRM framework uses demand, cost, and availability scenarios as critical inputs in the calculation of such expected values and standard deviations of future costs.

Different pieces of the information necessary to manage supply chain risks typically reside in different organizational functions, with few mechanisms available to connect and aggregate this information. For example, the information necessary to quantify demand uncertainty is part of the planning function, the market cost and available uncertainty part of the procurement function, and the inventory costs and margins part of the finance function. Our PRM business process links these functions and aggregates all information needed for risk management, thus institutionalizing risk management in the supply chain.

Cultural Challenges

Cultural challenges related to workforce skill sets further exacerbate the business process challenges. Most SCM professionals are not used to working with or quantifying the uncertainty in demand, cost, and availability of components. For example, while most professionals realize that demand forecasts include an element of uncertainty, few are able to quantify that uncertainty. To address this challenge, we developed a supporting infrastructure that includes a training curriculum and process consulting to help SCM professionals to understand and implement PRM. Meeting this challenge also required that we develop the PRM software with the analytics embedded behind an easy-to-use user interface.

The PRM Framework

To measure and manage procurement-related supply chain risks, HP has developed the following:

(1) A framework to quantify the impact of product demand, component cost, and availability uncertainty on revenue, costs, and profits;

(2) A suite of software tools, the HP Risk Suite, to support the risk-management process; this comprises HPHorizon demand-scenario software, HPRisk component-cost-forecasting software, and HPRisk contract-valuation software;

(3) A rigorous PRM business process to proactively manage procurement uncertainties and risks; and

(4) A training curriculum and consulting infrastructure to help HP professionals implement PRM.

Measuring Uncertainty Using the Scenario Approach

HP's PRM approach involves (1) measuring uncertainties associated with buying components, and (2) managing these risks using structured contracts.

The first step in this process is estimating uncertainties. Current forecasting approaches at most companies emphasize "point" forecasts (i.e., one number per time period). In contrast, the PRM process uses multiple forecast scenarios to capture the uncertainty of component demand, cost, and availability over time. Typically, each of these uncertainties is represented by high, base, and low scenarios. As Figure 2 shows, these are, respectively, the 90th, 50th, and 10th percentiles of a discrete-variable distribution at a particular time period. In addition, separate correlation coefficients are used to capture the relationship between demand and cost uncertainty, and between cost and availability uncertainty. These

![Figure 2: Scenarios in the graph quantify uncertainty in component demand, cost, and availability, as we illustrate here for demand forecasts. We define high, base, and low scenarios as the 90th, 50th, and 10th percentiles, respectively, of the uncertainty distribution for demand, cost, and availability.](image-url)
scenarios are multiperiod. After modeling these procurement uncertainties in this manner, the current procurement strategy can be analyzed to measure the procurement risks involved.

**HPHorizon Software to Quantify Demand Uncertainty**

Current demand-planning software systems capture and aggregate “point” forecasts for products and components. The analytics embedded in the HPHorizon software perform a regression analysis of historical forecasts and shipments to quantify forecast bias and uncertainty. The software then combines this information with current demand trends to represent the uncertainty in the demand forecast as high, base, and low scenarios. This software also determines and corrects biases in the point forecasts. HP’s planning team uses the HPHorizon software regularly to assess the uncertainty in demand forecasts for products and components.

**HPRisk Software to Quantify Component-Cost Uncertainty**

Hi-tech components, such as memory and LCD panels, exhibit significant cost uncertainty that, if left unmanaged, could significantly impact a company’s profitability. Measuring the uncertainty in the future cost of such components is the critical first step. The cost uncertainty of hi-tech components, which commonly demonstrate strong price momentum, makes previous price movements very significant factors in predicting future prices. In addition, hi-tech component prices typically demonstrate a long-term decline in costs due to technological and process-related improvements. The HPRisk cost-forecast software performs a regression analysis of historical costs for a particular component to determine the parameters of a non-Markovian price process using the scenario history to model the unique cost dynamics of each hi-tech component. These analytics have been individually adapted to components such as memory chips (flash memory), LCD panels, and plastics, and are embedded into easy-to-use software to forecast cost uncertainty using high, base, and low scenarios. The same analytics can be adapted to forecast cost uncertainty of other manufactured commodities such as chemicals or steel.

**Managing Risks Using Structured Contracts with Suppliers**

Once the demand, cost, and availability uncertainties are quantified using scenarios, the risks associated with these uncertainties are managed by setting up portfolios of structured contracts that HP executes directly with suppliers. These are binding commitments, incorporating a complex combination of quantity and pricing terms. Quantity terms include fixed and flexible quantities, and percentage of total available market (TAM); pricing terms include discount-off-of-market price, fixed price, price caps, and price floors.

**Applying the Structured-Contract Approach to Manage Risk**

To illustrate the use of the structured contract to manage risk, consider the schematic in Figure 3.

We represent the demand uncertainty using low, base, and high scenarios. Given that the low scenario is the 10th percentile of the demand distribution, the likelihood that the actual demand will be greater than this number for a given period is very high—in fact, an estimated 90 percent. For such “nearly certain” segments of demand, HP would commit to buying today, at time = 0, a fixed quantity from one or more suppliers for a longer period of time. The probability that demand will be at least large enough to fall in the range above the low scenario to approximately the base scenario is lower; therefore, for this range, HP executes a flexible-quantity commitment wherein a supplier commits today to supplying any quantity.

![Figure 3: Demand scenarios can be used to contract differently with suppliers. Based on the certainty of a demand segment, HP executes fixed- or flexible-quantity structured contracts with one or more suppliers.](image-url)
that HP chooses to buy within that range and at HP’s option. For the segments of demand above the base scenario, where the probability that demand will be at least that large is lowest, HP does not make any commitment today to buy and the suppliers do not commit to supply any quantity in this range by contract. Instead, HP will use existing suppliers or the spot market to meet such high demand if and when that demand exists in a future time period even though the spot market price will be higher than the contracted one. In this simple illustration, the portfolio of contracts is composed of fixed-quantity and flexible-quantity contracts, with a portion of uncommitted demand.

To address specific business objectives, such as cost savings or cost predictability, these quantity terms are paired up with specific pricing terms. For example, if the business objective is cost savings, then the fixed-quantity and/or flexible-quantity terms are combined with a discount-off-of-market-price pricing term. If the business objective is cost predictability, then the fixed- and/or flexible-quantity terms are combined with either a fixed-price or price-cap pricing term. Price-cap contracts establish upper limits; therefore, if the market price is higher than the price cap, HP pays the price cap, and if the market price is lower than the price cap, HP pays the lower market price.

Effectively, the portfolio of structured contracts is composed of contracts that combine quantity and pricing terms to maximize business objectives—resulting in “tailored” structured contracts—and to manage risks due to demand, cost, and availability uncertainty.

Compare this portfolio-of-contracts approach to the common practice of manufacturing companies of not committing any volume to suppliers, providing only nonbinding forecasts of demand to help suppliers plan their production. In an attempt to ensure supply, and with nothing to lose, manufacturers have an incentive to inflate the nonbinding forecasts. As a result, suppliers have little faith in a manufacturer’s ability to order based on the forecast; therefore, they plan to produce fewer components than the manufacturer’s forecast to reduce their risk of excess inventory or capacity. Because of this lack of commitment upfront on pricing or supply terms, the procurement uncertainties are exacerbated over time, especially in a volatile industry such as electronics.

The fundamental value of the PRM approach is the structured sharing of risks between HP and the supplier. This is driven by the ability of one party to better manage certain risks and to be rewarded fairly for it. For example, HP can better accept risks due to uncertain demand for its products than one of its suppliers can. By entering into a quantity commitment with a supplier, HP bears this demand risk and, in turn, the supplier rewards HP with better pricing terms. In cases where a supplier explicitly manages quantity and especially pricing risks, HP rewards the supplier with better quantity and/or pricing commitments. This contrasts with traditional industry practices where buyers do not make quantity commitments; therefore, they impose all demand risk (and associated costs) on the supplier.

For buyers and commodity managers, segmenting demand increases opportunities for creative contracting with suppliers. Suppliers are often willing to provide a discount for fixed-quantity commitments because it allows them to manage their production, capacity investments, and their own supply agreements more efficiently. They can schedule committed volumes during nonpeak times, and inventory carries no obsolescence risk. On high-volume deals, suppliers can modify fabrication lines to significantly reduce costs.

HPRisk Contract-Valuation Analysis
Because the PRM approach is based on forward-contract commitments to price and quantity terms, it is critical that these contracts be appropriately analyzed to increase benefits and decrease the risk that the contracts will incur costs (for given levels of availability) in excess of short-term sourcing alternatives. Complicating this analysis are situations where for a given commodity there are several overlapping contracts, each with different quantity, pricing, and cash-flow structures. The value of a contract may depend greatly on the other contracts that are in place. Given such a portfolio of structured contracts, the optimal quantity to be bought from the different contracts at any period in time will depend not only on the current demand, price, and availability, but also on the specific structure and terms of the other contracts.
The HPRisk contract-valuation analytics (Figure 4) use an optimization engine to determine the optimal purchase in each period and scenario combination; therefore, they ensure that a correct value is placed on the flexibility from the contract portfolio. In our case, the decision variables are simply the quantities to buy from each contract or from short-term sourcing. The objective function adds material, shortage, and inventory costs, so that the OEM automatically finds a contract mix to optimize trade-offs among these costs to find a minimum expected total cost across scenarios. Constraints are included to represent minimum and maximum contract purchase quantities and the maximum availability through short-term sourcing. These max/min quantities are contract specific and determined through supplier negotiation. The optimization engine is run in each period and scenario combination, and reports are returned for the optimal purchase quantities and cost metrics in each case. Then, engine can be described schematically as:

**Decision variables:** The quantities to buy from each structured contract and/or from short-term sourcing in each period and scenario combination.

**Objective function:** Minimize expected total cost, with the total cost in each period and scenario combination represented by the sum of the material, shortage, and inventory costs in that period and scenario combination.

**Constraints:** (1) Minimum and maximum contract purchase quantities and the maximum availability through short-term sourcing in each period and scenario combination, and (2) nonnegative quantities purchased for each structured contract.

The contract-valuation analytics have been incorporated into easy-to-use software—HPRisk Contract Valuation. This software automates calculations across a full range of price, demand, and availability scenarios that are required in measuring procurement risks; it also supports “what-if” analysis to explore alternative contract terms and comparisons between alternative contract portfolios to aid in the negotiation and financial due diligence of complex sourcing contracts.

The PRM Business Process

Risk management by its very nature is a cross-functional process. We have developed a cross-functional PRM business process that links and defines the roles and responsibilities of procurement, planning, supply chain operations, finance, and marketing. HP’s risk-management process is simple in structure but rigorous in execution (Figure 5).

Strategy and governance for a particular commodity typically include approving procurement objectives, establishing metrics, and reviewing the performance of any existing portfolio of contracts. HP manages strategy and governance for product-specific commodities at the business-unit level; it manages commodities that are common across products more centrally. The deal-origination process guides the design of portfolios of structured contracts to meet procurement objectives and to manage current product and component market uncertainties. For company-wide contracts, commodity managers specify contract terms that satisfy specific product or divisional objectives, and a team of commodity managers...
integrates these specifications into a single contract to leverage purchasing power.

HP uses the HP Risk suite of software tools to evaluate the performance of the proposed portfolios of structured contracts during the contract-evaluation phase to determine their future performance against set objectives under various conditions of demand, price, and supply uncertainty. We pay specific attention to situations under which a contract would perform worse than buying on the spot or short-term market without binding terms and conditions. The contract origination and evaluation phases are iterative, with the latest analysis guiding the redesign of the proposed contracts being negotiated with suppliers; the iteration stops when the analysis determines that the proposed portfolios of structured contracts meet the set objectives. Once the proposed contracts are approved, these contracts are negotiated and executed using traditional face-to-face methods or over the Internet using reverse auctions.

The contract monitoring process guides (1) the backward-looking measurement of HP’s and suppliers’ performances against commitments made in the structured contracts, (2) the determination of the past performance of a structured contract (or combination of contracts) when compared to previously established metrics, and (3) the future performance of an existing portfolio of contracts under changed forecast scenarios for demand, price, and availability.

HP has instituted a rigorous process to estimate demand, price, and availability uncertainty for forecast-scenario generation. The forecasting process forms the cornerstone of HP’s risk-management process because credible forecast scenarios drive contract valuation and monitoring processes. The forecasting process involves estimating uncertainty by analyzing historical demand, price, and availability data using the software tools we described earlier, and modifying these estimations of uncertainty using input from market analysts on price and availability uncertainty and HP component-demand uncertainty. Analyzing the impact of new forecast scenarios at the start of each new time period on an existing portfolio of contracts identifies any unmanaged risks; these risks are then addressed at the deal origination phase, thus restarting the cycle all over again.

Each business unit’s vice president for supply chain management leads the PRM business process and sets the procurement objectives as a part of the strategy and governance activities described earlier. At the pan-HP level, HP’s Supply Chain Board sponsors the PRM program. This board comprises senior vice presidents of HP’s three global business units—Printers, PCs, and Servers—who set and monitor PRM implementation objectives for the various commodities and business units.

PRM Implementation Benefits

Portability of the PRM Approach
Over the past six years, HP has been successful in developing and deploying an OR-based procurement risk-management framework, business process, and software, and in implementing the risk-management approach across HP’s business units for the procurement of key strategic commodities. HP has applied PRM for a range of procurement situations ranging from direct procurement of components to indirect and services procurement. In direct procurement, HP has applied PRM to standard components, such as memory, hard disk drives, and plastics, to custom components, such as microprocessors, application-specific integrated circuits (ASICs), and custom assemblies. In indirect and services procurement, HP has applied PRM to energy, spare parts, and advertising procurement.

In general, we designed the PRM approach to address questions such as: “How much should we buy?,” “When and for what time frame?,” and “At what price?,” in the face of uncertainty in the business environment. Because these questions are common across all industries, the PRM approach, analytics, software, and processes are portable to all manufacturing industries. The wide range of applications of PRM across HP’s different commodity categories illustrates the power, generality, and portability of the PRM approach. HP has received requests from several companies to share this methodology. Some have even requested consulting services on this subject, and HP intends to start a consulting service focused on commercializing our PRM approach and tools.
Benefits

We describe the benefits of implementing PRM below:

(1) Material-cost savings: HP obtained $128 million in material-cost savings in FY’06, and over $325 million in material cost savings (and $425 million in total costs savings from all categories) cumulatively over the past six years using the PRM approach. PRM quantity commitments lowered suppliers’ demand risks, while also enabling suppliers to cut costs through more efficient planning and production processes. The suppliers share some of this value with HP through discounts on material costs, through discount-off-of-market-price pricing terms. Through such PRM quantity commitments, HP obtained material-cost discounts of up to five percent for standard components, when compared to market prices, and an even higher discount for custom components, and indirect and services procurement.

(2) Assurance of supply: Managing component demand and availability uncertainties is a key PRM objective at HP. PRM contracts have improved supply availability for several commodities—even under industry-wide shortage conditions. For example, despite an industry-wide memory shortage approximately one year ago, the PRM contracts that HP business units had executed ensured that they obtained 100 percent of their demand from the suppliers. We estimate that HP obtained more than $50 million in additional margin through PRM contracts that ensured component availability in market-shortage conditions over the past six years.

(3) Cost predictability: PRM contracts with specific pricing terms enable HP to manage cost uncertainty proactively. HP now procures over 25 percent of its memory chips using PRM contracts; this enables HP to obtain the cost predictability required to protect margin on contracted sales to large customers. We estimate that HP achieved cost savings of more than $50 million when market prices for memory moved higher than the fixed prices and price caps specified in the PRM contracts over the last six years.

(4) Inventory reduction: The requirement for HP to hold inventory is reduced as suppliers commit to providing defined upside flexibility through flexible-quantity contracts. In one instance, HP used to carry three months worth of inventory of a custom semiconductor component to mitigate an expected shortage; using PRM, it was able to replace this “strategic” inventory with a flexible-quantity contract executed with that component’s supplier. In addition, the precise measurement of demand uncertainty using PRM software enables HP to optimize inventory levels internally and externally at supplier sites. Thus, implementing the PRM approach has reduced inventory-driven costs for commodities by several percentage points.

(5) Supplier benefits: Given the risk-sharing aspects of PRM, the suppliers have also benefited substantially. The quantity commitments that HP makes to suppliers, as opposed to just exchanging nonbinding forecasts, have lowered suppliers’ risks (Shah 2002); suppliers of several strategic commodities have locked up significant portions of their capacity through PRM contracts with HP.

(6) Reduction in the “bullwhip effect”: Some suppliers are making commitments to their suppliers (who are HP’s second-tier suppliers) that are tied to HP’s quantity commitments to them. This results in quantity commitments that cascade deeper into the supply chain, resulting in a significant drop in order volatility through the supply chain; thus, this results in a reduction in the “bullwhip effect.” We have observed reductions in order volatility of up to 50 percent across two tiers of the supply chain after implementation of the PRM approach. The first tier is between HP and our supplier; the second tier is between our supplier and their supplier. Therefore, the PRM approach has the effect of smoothing supply chain volatility.

(7) New business process and PRM function: As we described above, we have developed a cross-functional business process that makes risk management a regularly scheduled activity that ensures that risks are continually identified and managed. This business process also ensures that the benefits from implementing PRM are ongoing. Some HP business units have instituted a “PRM Manager” position, a new business position much like manager of procurement, planning, or finance.

(8) HP workforce development: Because the PRM approach is still new at HP, we have developed supporting infrastructure that includes a training curriculum.
and process consulting to help the commodity, planning, finance, and marketing managers learn and implement PRM. Over 1,000 HP employees and senior executives have undergone PRM training courses. This training has the potential to magnify the benefits already obtained from PRM.

Figure 6 shows the direct impact that PRM has had on HP's spending and the cost savings it has enabled over the last six years.

Summary of Key Innovations

The OR-based PRM approach represents a paradigm shift in how HP manages its supply chain. Its successful implementation required several innovations in analytics, software, and business processes. We summarize some of the key innovations below.

1. Development of a scenario-based approach to quantify the uncertainty pertaining to multiperiod and correlated demand, cost, and availability uncertainties to measure risk in the supply chain. The methodology incorporates the analytics to quantify demand and cost uncertainties in easy-to-use software packages—HPHorizon demand-scenario software and HPRisk component-cost forecasting software. Supply chain professionals require minimal training to use these packages.

2. Development of a risk-sharing portfolio-of-structured-contracts approach to manage the multiperiod risks associated with demand, cost, and availability as a portfolio. This represents a new paradigm for writing contracts in the supply chain.

3. Development of analytics to determine the portfolios of structured contracts that best meet a defined set of business objectives. We incorporated those innovations in the HPRisk suite of PRM software; this has resulted in five patent applications thus far.

4. Development of cross-functional business processes involving planning, procurement, and finance to institutionalize the management of supply chain risks.

5. Most importantly, the above innovations have the appropriate level of sophistication and ease of use to enable HP to be one of the first manufacturing companies to widely implement a modeling-based risk-management approach to proactively manage the multiperiod and correlated demand, cost, and availability uncertainties in its supply chain.

All parties in the supply chain benefit from reductions in volatility; in particular, suppliers pass some of the benefits as cost savings to HP. This paradigm shift that the PRM approach has enabled now provides a recurring savings stream of approximately several percentage points to HP. Thus, PRM is transforming HP's internal planning, procurement, and supply chain processes, and its relationships with its suppliers through a win-win risk-sharing partnership.

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