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Formulation of a Production Strategy for a Software Product Line

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Table of Contents

Abstract **vii**

1 Introduction **1**

2 Production Planning **3**

3 Porter's Five Forces Model **5**

4 Production Scenarios **7**

5 Formulating a Production Strategy **9**
5.1 Identifying the Critical Factors 9
5.1.1 Market Analysis 10
5.1.2 Building a Business Case 10
5.1.3 Scoping 10
5.1.4 Technology Forecasting 11
5.1.5 Understanding Relevant Domains 11
5.2 Formulating the Production Strategy 12
5.2.1 Generic Strategies 13
5.2.2 Integration 13
5.3 Example Production Strategies 14
5.4 Evaluating and VErifying the Production Strategy 16

6 An Example **18**
6.1 Define production scenarios 18
6.2 Identify the critical factors 19
6.3 Formulate the Production Strategy 20
6.4 Evaluate the strategy 22

7 Summary **23**

Bibliography **25**

List of Figures

Figure 1: Production Planning 3

Figure 2: Porter's Model of Forces Driving Industry Competition 5

Figure 3: Technique Overview 9

List of Tables

Table 1:	Porter's Forces	6
Table 2:	Production Scenario Format	7
Table 3:	Strategic Forces	12
Table 4:	Initial Production Scenario	18
Table 5:	Product Line Production Scenario	18
Table 6:	Portability Scenario	19
Table 7:	AGM's Critical Factors	19
Table 8:	AGM’s Strategic Actions	21
Table 9 :	Evaluation of AGM's Strategy	22

Abstract

Software product lines are of strategic importance to the organizations that adopt them, affecting both an organization's position in an existing market and its ability to react to new and changing markets. An organization's production system (i.e., how it builds its products) is also of strategic importance, directly affecting, for example, that organization's ability to deliver new products quickly (i.e., its time to market).

The production strategy for a software product line is the high-level description of how the production system realizes both the core assets and products. The production strategy is derived from the organization's business strategy and is intended to coordinate the actions of the core asset and product developers. The strategy describes how the product line practices should be employed so that the product line organization will achieve its production goals. This technical note describes a technique, which is based on well-known procedures for defining and evaluating a business strategy, for formulating the production strategy of a production system. An example of strategy creation is provided.

1 Introduction

A business strategy is "the pattern or plan that integrates an organization's major goals, policies, and action sequences into a cohesive whole" [Quinn 1980]. Rumelt states that strategy is about the direction of organizations:

> *It includes those subjects which are of primary concern to senior management, or to anyone seeking reasons for the success or failure among organizations. Firms have to make choices to survive. Those which are strategic include: the selection of goals, the choice of products and services to offer; the design and configuration of policies determining how the firm positions itself to compete in product markets (e.g., competitive advantage); the choice of an appropriate level of scope and diversity; and the design of organization structure, administrative systems and policies used to define and coordinate work. It is a basic proposition of the strategy field that these choices have critical influence on the success or failure of the enterprise, and, that they must be integrated. It is the integration (or reinforcing pattern) among these choices that makes the set a strategy [Rumelt 1991].*

An effective organization has many strategies, each of which aligns with the overall business strategy. The critical factors mentioned above refer to both market conditions that affect an organization and how an organization's products can affect the market. The production strategy describes the production factors critical to the success of the product line and specifies an overall approach to addressing those factors.

Software product lines can improve an organization's position in an existing market and its ability to react to new and changing markets. Product lines are of strategic importance to the adopting organizations. The production strategy is critical to the success of that product line. For example, an organization might choose to develop products quickly to react to new market opportunities or rapidly emerging market threats, or to develop easily customized products to target a specialized market niche. This technical note describes a technique for developing a production strategy by

- eliciting and documenting an organization's requirements for the production system (i.e., how a product line organization chooses to develop its products) as a series of scenarios
- identifying the production factors critical to the success of the organization's product line by relating the organization's key challenges for the product line to the strategically significant product line practice areas
- identifying strategic actions that address those critical factors
- refining the strategic actions into a coherent strategy based on established business strategy development techniques such as Porter's Five Forces [Porter 1998]
- evaluating that strategy using Rumelt's four criteria for business strategy evaluation, as described in Section 5.3 [Rumelt 1991]

The production scenarios cut across the product line practice areas [Clements 2002] to define how the production system operates. The scenarios provide the context in which the critical factors are considered. Those factors constrain the strategic actions that can be deployed in the production strategy.

The intended audience for this technical note is anyone who develops, or is responsible for developing, products or product parts (e.g., core assets) in a software product line, including product

managers, product line managers, analysts, system engineers, architects, and method and process engineers.

The rest of this technical note is organized as follows:

- Section 2 briefly describes the role of the production strategy in the larger context of production planning for a software product line.
- Section 3 introduces Porter's five forces model.
- Section 4 defines production scenarios.
- Section 5 describes our technique for formulating a production strategy.
- Section 6 provides an example of the application of the technique.
- Section 7 summarizes this technical note.

2 Production Planning

In a software product line, the products are developed using the core assets. The production strategy is formulated as part of production planning, which balances the goals and constraints of a product line to ensure that the core assets effectively support product development.

Product production is viewed as a system that is engineered to have specified qualities including the predictable building of intended products. The core assets and product development activities must be jointly engineered to achieve the organization's goals for the software product line. The goal of production planning is to produce a strategy, method, and plan, thereby reducing the risk of inconsistencies between core asset and product development.

Production planning is of strategic importance to the product line organization. How an organization develops products affects its position in the market place; how it designs its core assets affects its ability to address new markets and to respond to emerging threats [Chastek 2007]. The production capability of a software product line realizes the ability to meet business goals. Without a production plan, an organization has core assets but no prescribed way to use them to predictably meet the business goals.

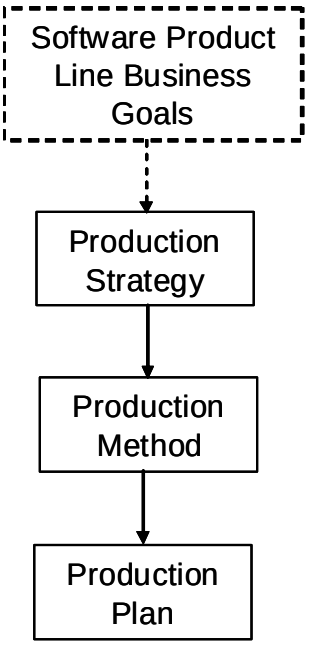

Figure 1: Production Planning

Figure 1 illustrates production planning for a software product line:

- The production strategy determines how product development satisfies the organization's goals for the software product line and integrates the goals, policies, and actions of the product line organization for product production.
- The production method, as the overall implementation approach, determines what processes, models, and technologies can be used to ensure consistency and the necessary variation across the core assets based on the production strategy. The production method provides the

required coordination of the core assets and product development activities. This coordination includes assuring that the three essential product line activities—core asset development, product building, and management—each operate at an appropriate tempo so the three interact efficiently.

- Finally, the results of the production planning are documented for the product developers in the production plan that describes what the product developers need to know to effectively use the core assets to develop products with predictable results [Chastek 2002a, Chastek 2002b].

This report describes the strategy formulation portion of production planning.

3 Porter's Five Forces Model

Many of the production goals for a software product line are driven by the actions and activities of the organization's competitors. Michael Porter produced a widely used model that addresses competitive strategy [Porter 1998]. Porter's intent was to establish a strategy that provides competitive advantage for the organization using the model. Porter classified the competitive forces acting on the organization into the five categories shown in Figure 2.

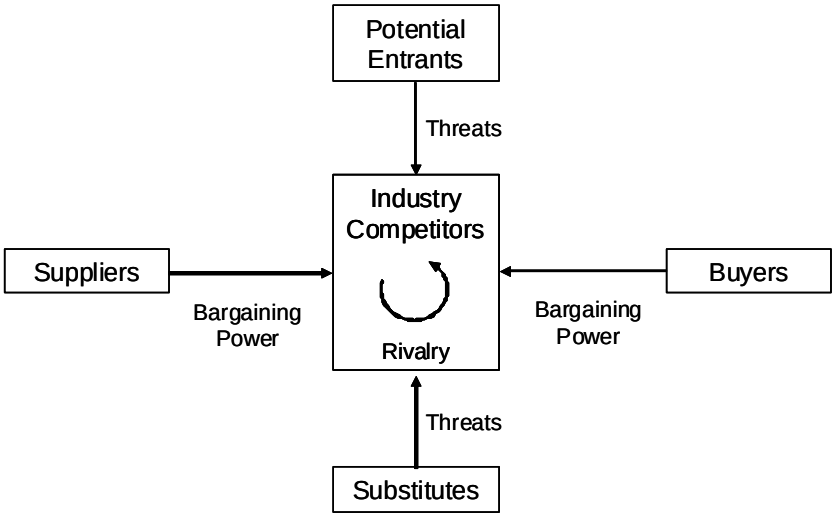

Figure 2: Porter's Model of Forces Driving Industry Competition [Porter 1979]

The organization uses the model to guide its business strategy development. The organization determines the forces at work in its specific business environment and proposes actions that would address those forces, ultimately synthesizing a competitive strategy from the selected action.

In Table 1, we situate Porter's model in the context of a software product line organization. We also begin considering how each force applies to product production by asking an example question about the meaning of each force in a product line production environment. In practice, many such questions need to be asked.

Table 1: Porter's Forces

Force Name	Porter's Definition	Examples of Product Line Context Questions
Industry Competitors	those organizations that are addressing the same market need or mission as yours	How can we gain advantage over the competition by choosing different production techniques?
Potential Entrants	a product or service that might become available to be used in place of yours	How can we raise the cost to others of entering the market by the means we use to produce the products?
Buyers	those who are currently purchasing your product or service	How can we more quickly respond to buyers' requests through attributes of the production process?
Substitutes	a currently available product or service that could be used in place of yours	How can we differentiate our product from the substitutes through the means of production?
Suppliers	those who provide some portion of the content of your product or service	How can we lower the prices we pay suppliers by the production techniques we use?

In Section 5 we incorporate this business strategy development model into our technique for creating the production strategy. In addition to the model, Porter identifies three generic strategies: cost leadership, differentiation, and focus that resolve the five forces. These strategies are defined and discussed in Section 5.2.

4 Production Scenarios

Product production in a software product line can be viewed as a system in its own right, the so-called production system. The primary input to that system is a description of the product to be developed while the primary output is the requested product. As with any system, the production system has associated functionality and qualities that can be described using scenarios. For example, the tools used in product development are the functions of the production system. More relevant to the production strategy are the qualities of the production system (i.e., the production qualities). Performance is a typical example, usually expressed as time to market (i.e., the time from receipt of a product order until that product is delivered). Flexibility, the ability to deliver customized products, is another such example. Production scenarios express the different circumstances under which products will be built from the core assets. The scenarios provide a high-level view of the development process, deferring specific details until the strategy is developed. These scenarios are used to both

- explore the required characteristics of the production system, such as the production qualities needed to satisfy the product line business goals and
- ensure that the production strategy is formulated with sufficient breadth and depth to address the needs of the complete product line

We have adopted the scenario format used for quality attribute analysis for guiding the development and evaluation of software architectures [Bass 2003]. A scenario takes the form of a stimulus/response with a description of the context within which the action occurs. A scenario description is decomposed into the six sections listed in Table 2.

Table 2: Production Scenario Format

Scenario Element	Product Line Interpretation	Example of Scenario Element
Stimulus	The event or action that affects the development of a product	A requested product requires a new target platform.
Source of Stimulus	Who or what is initiating the production of this product	A customer requests a new product feature.
Environment	The state of the production capability of the product line at the time of this scenario; for example, all core assets are completed and available for use	Product development has become routine.
Artifact	The artifact acted upon; this can be the product being produced or a core asset being used.	The artifacts can be new product-specific or existing core assets for the new platform.
Response	How the production system responds to the request to produce a specific product; for example, how long will it take to produce this product?	The requested product is developed successfully.
Response Measure	Some common response measures are calendar days from purchase contract to deployment, cost in dollars, or days of effort.	The requested product is delivered in less than two days from the time of its request.

Production scenarios are used to

- refine the critical factors (see Section 5.1) associated with the production system
- create a prioritized list of production qualities[1] that is used during strategy development to resolve conflicts among strategic actions that have inconsistent effects on the product line
- verify that the production strategy selected satisfies the business goals of the product line

Testing-style coverage techniques are used to define the set of scenarios. For example, where two products will be built differently, the organization determines what causes the difference and identifies scenarios that address the circumstances under which each technique is used.

Each event or action that initiates the development of a product may be analyzed in terms of one or more scenarios. The set of scenarios is defined to achieve the following:

- Each scenario addresses the production system's response with respect to a single production quality in a specific situation.
- Each development approach is exercised in a sufficient number of scenarios to explore all of its variations.
- Each production quality attribute is exercised in a sufficient number of scenarios to address the full range of values for the attribute.

[1] Chastek defines production qualities and describes how to elicit and analyze them [Chastek 2003].

5 Formulating a Production Strategy

The technique for formulating a production strategy is shown in Figure 3. The organization examines the work products of the strategically significant product line practice areas (described in Section 5.1) to identify additional factors and trends critical to the success of the organization's product production. Those factors and trends are consolidated into a production strategy using Porter's Five Forces model. The strategy is then evaluated using Rumelt's four criteria. Production scenarios are used in each step of the technique to determine precisely what that goal means for the production system.

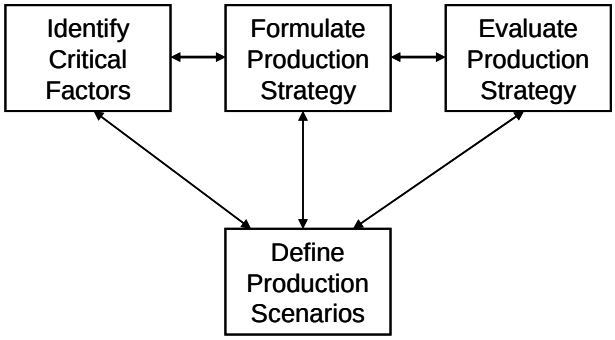

Figure 3: Technique Overview

The production strategy is developed iteratively starting with identifying the critical factors. The critical factors have many interactions, and identifying new factors may influence the other factors identified previously. Additional iterations are necessary to resolve these influences and modify the strategy to ensure a consistent and coherent strategy. All too often, this iteration occurs because a problem is encountered very late in the cycle. Measurement and tracking can give early warnings by looking for attributes that fluctuate or for sections of the production plan that generate an extraordinary number of problem reports. Since the critical factors can change over the lifetime of the software product line, the production strategy evolves. Changes in the strategy are propagated through the production process.

5.1 IDENTIFYING THE CRITICAL FACTORS

In the Rumelt quote in Section 5.3, the critical factors mentioned are associated with strategic opportunities and threats, the quality of long-term results, measurability and flexibility for effective and timely responses, and ultimately organizational success. Presumably, the organization's strategy for choosing a software product line approach identifies relevant critical factors that will affect the production strategy. These critical factors can describe an organization's potential positioning in a market, or they can constrain that organization's efforts to position itself in that market.

The successful prosecution of the product line practice areas identifies an organization's critical product line success factors [Clements 2002]. Potentially, any of the 29 practices areas can be the source of factors or trends that can affect the production strategy. However, certain practice areas are directly tied to the product line organization's business goals and hence are vital to the formulation of the production strategy, while other practice areas primarily constrain or refine that strat-

egy. This section discusses the practices areas used in the What to Build pattern, which have typically been applied in the earliest planning stages of a software product line [Clements 2002].

5.1.1 Market Analysis

Market analysis is the systematic research and analysis of the external factors that determine the success of a product in the marketplace [Clements 2007]. The market analysis contains information about buyers of the product line's products as well as current competitors and potential entrants into the market. The analysis identifies the features of the products purchased by members of the target audience. This analysis provides the strategists with predictions of which features products must provide immediately and gives a prediction of the evolution of the feature set.

Example of a critical factor: the demand for a particular feature may not justify costs associated with particular production techniques. For example, the market analysis in a technical organization, such as an original equipment manufacturer (OEM), will often examine how customers expect their products to be built. A customer might require a specific Capability Maturity Model Integration (CMMI) level of certification to provide additional confidence in the quality of the products. Moving the organization to that level may simply not be justified based on the customer's anticipated sales volume.

5.1.2 Building a Business Case

A business case addresses the following key questions that an organization faces when planning major changes in how it does business:

- What specific changes must occur?
- What are the benefits of making the change?
- What are the costs and risks?
- How do we measure success? [Clements 2007]

The business case defines the boundaries within which the production system must operate. Factors affecting the production system arise in the business environment such as the rhythm at which the business operates, how often products will be released, and how rapidly products in the domain are changing.

Example of a critical factor: the time horizon for refreshing products. Essentially, the lifetime of a product influences the production strategy. For example, most people expect to exchange their cell phones every two years to get a new model with many new features. Can the long-term production strategy support that rate of product release? A few years ago, the answer was no. By changing its means of production, one cell phone manufacturer was able to decrease the time to produce a product, while also reducing the staff required by the production process.

5.1.3 Scoping

Scoping is the activity that bounds the set of systems that compose the product line by defining those behaviors or aspects that are "in" and those behaviors or aspects that are "out" [Clements 2007]. The product line scope provides factors that constrain the operation of the production system. Determining the scope provides a basis for determining the variations, and hence the binding times, that will be most important to the success of the product line.

Example of a critical factor: the influence of the product line's homogeneity on the production strategy. If one product requires a very different production process from the rest of the product line, its expense should be balanced against the reasons for including the product in the product line. Real-time, embedded products require activities such as performance modeling and instance tuning. If some of the products in the product line are for mobile devices and require the real-time techniques and others are data-intensive applications that require database tuning, the production strategy will be more complex with more decision points.

5.1.4 Technology Forecasting

Technology forecasting addresses trends in two areas:

1. technologies that support internal software development, which includes tools, processes, and methods for producing the software that will end up in products
2. customer solutions, meaning technologies that will affect (or end up as) features or capabilities embedded in products [Clements 2007]

The technology forecast provides information about substitutes for the product line's products, suppliers to the product line, and to a lesser extent, potential entrants into the same market. The technology forecast provides a look at both domain-related technologies and product-building technologies. The latter forecasts enable the strategists to anticipate the evolution in building techniques and tools. In some cases, the introduction of a feature may be timed to coincide with the availability of certain tool capabilities. For example, the use of introspective techniques used in some self-adaptive systems was facilitated by the introduction of languages with reflective capabilities.

Example of a critical factor: The technologies used to produce a product make a difference to certain types of technical customers. The people who market products to them are a valuable source of information regarding their customers' technology concerns. These concerns should influence the production strategy. For example, when Java first emerged, it was viewed by some as a web programming language that would be used in applications where time and space were unimportant. A few vendors of micro-platform products such as cell phones saw the potential. Today, most application packages running on top of cell-phone platforms are written in Java. Companies with Java expertise have been able to capitalize on that.

5.1.5 Understanding Relevant Domains

The practice of understanding the relevant domains involves

- identifying the areas of expertise—domains—that are useful for building the product or products under consideration
- identifying the recurring problems and known solutions within these domains
- capturing and representing this information in ways that allow it to be communicated to the stakeholders and used and reused across the entire effort [Clements 2007]

Modeling techniques such as product line analysis are based on a broader analysis than that of the current market or target audience [Chastek 2001]. Product line analysis considers the full scope of products that are currently available and those that are anticipated. It defines and bounds the variation across the products of the product line as well and define a vocabulary that the core asset developer and product developers can use to communicate. The analyst identifies optional features by

considering the feature sets of competitors, their projected upgrade paths, and standards efforts. The information captured includes information about production qualities such as binding times.

Example of a critical factor: the velocity at which a domain is changing. The product line organization must balance planning horizons with the rate at which fundamental knowledge is becoming obsolete. Areas such as service-oriented architectures and grid computing are changing at a rate that makes production planning for products, even a couple of years ahead, very risky. The higher the velocity, the more flexible the production strategy must be.

5.2 FORMULATING THE PRODUCTION STRATEGY

We use Porter's Five Forces model to transform the critical factors and production scenarios into a set of strategic actions (actions that affect the organization's position in its market) that specify the capabilities of the production system [Porter 1998].

Each force is examined in the context of the production scenarios. The business goals and the results of the market analysis and technology forecasts, as noted in Section 5.1, provide information that can be used to select the strategic actions the product line organization should take to address these scenarios. The priorities among production qualities are used to filter and prioritize the strategic actions.

We impose a meaning on each force by specifying the strategic actions that would help resolve each force. Table 3 lists the forces and corresponding potential strategic actions for resolving them. The examples of strategic actions in the third column of Table 3 show how the actions can be used to develop a production strategy.

Table 3: Strategic Forces

Force	Strategic Actions	Examples of Strategic Actions
Substitutes	Raise switching costs. Increase brand loyalty.	Reduce production costs to enable us to lower prices and make substitute products unattractive.
Potential Entrants	Raise cost of entry. Utilize economies of scale.	Reduce the cost of mass customization by automating product production.
Buyers	Differentiate products. Exert bargaining leverage.	Establish a sufficiently flexible production system to meet the varying demands of buyers.
Suppliers	Exploit volume of products. Differentiate inputs.	Use the economies of scale in a product line to leverage purchases of tools and components.
Competitors	Exploit relationships. Improve features and innovating.	Adopt production techniques that support rapid changes to existing features and rapid introduction of new features.

The organization forms the strategy by selecting actions to resolve each of the five forces separately and then resolving any conflicts among the selected actions.

5.2.1 Generic Strategies

Porter identified three generic strategies that aid the formulation of a production strategy:

1. cost leadership: Provide the lowest cost product for a given market and level of product quality. A product line organization is usually in a position to adopt this strategy as the strategic reuse made possible through a product line greatly reduces the amount of software needed to build a specific product. Also, the separation of core asset development from product development (which is one possible organization) allows for a differentiated work force. That is, less skilled, and presumably lower paid, workers can produce the products using assets designed by a smaller, but more highly skilled, core asset team.
2. differentiation: Offer products or services that are perceived as unique and valuable. A product line organization can differentiate its products in many ways. From a production perspective, the two most apparent ways are through mass customization and reduced time to market. The market analysis provides information about required and desired features as well as needed time to market to outpace competitors. A well-defined set of variation points allows a product line organization to differentiate itself from its competitors and to provide a wider range of products by composing features in many different combinations instead of a few standard combinations.
3. focus: Concentrate on a narrow market segment and pursue cost leadership or differentiation within that segment. A product line organization carefully scopes the set of products based on business priorities to focus on specific product feature sets. The scoping activity provides the opportunity to adjust the focus due to changing conditions and forecasts.

For an example of applying a generic strategy, consider the “substitutes” force and the accompanying strategic actions in Table 3. One possible strategy is to adopt the differentiation generic strategy: specifically to reduce the time to market a new product. An organization might implement this type of strategy by making portability a quality attribute of the product line architecture and by using a language such as Java that supports fine-grained product structure. Very little of the product has to be recompiled, and even the new deployment package is virtually unchanged.

5.2.2 Integration

Once identified, the strategic actions must be examined as a group and integrated into a coherent, cohesive strategy.

- Examine the set for inconsistencies. Two actions that have opposite effects on the product line must be resolved by yielding to the production quality that has a higher priority.
- Actions that share a common theme can be grouped into an encompassing action.

The resulting strategy should be easy to understand and give clear direction to the core asset and product developers. For example, consider the actions for Substitutes and Suppliers in Table 3. Both of these actions call for a reduction in costs. The resulting strategy would call for reducing the cost of tools, training, and other production expenses. The Buyers and Competitors actions are focused on flexibility. The production strategy would call for low-cost, configurable tools.

5.3 PRODUCTION STRATEGY EXAMPLES

What are some standard production strategies that are used, or could be used, in the production strategy of a software product line organization?

1. **Be open.** Use open source software and contribute to open source projects. Ultimately your organization might choose to start a new open source project to get exactly what it needs [Mebane 2007]. This strategy lowers the boundaries of the organization and stimulates the flow of assets into and out of the core asset base. The organization assigns people to survey existing open source projects and, in some cases, to participate in appropriate open source efforts. The organization can take advantage of their employees' outside affiliations to be aware of the directions of open source projects and to influence those directions where possible. This strategy affects core asset production more than product building. The production method, based on this strategy, will provide techniques for certifying some open source software to be added to the core asset base as is and techniques for extending and integrating the open source contributions to fulfill the needs of the core asset base. The portion of the production plan related to development of the unique portion of a product directs product builders to search available open sources before building a new asset and encourages teams to consider which, if any, of the assets created during product production might be appropriate for sharing with the wider community.
2. **Be evolutionary.** Include the user in the development process by providing early releases of minimal functionality to stimulate feedback [Bosch 2002]. This strategy explicitly defines a roadmap of successive expansions of the core assets' capabilities. The strategy eventually produces a full set of assets including documentation and management plans. The production method describes how to incorporate the feedback of actual users working with early prototypes. This strategy is iterative and incremental at the level of the core asset base. Each asset evolves to a degree of completeness that is useful. The production plan maps out how to maintain consistency among the assets as they evolve somewhat independently.
3. **Be agile.** Develop very small increments before stopping to assess and chart future directions. Doing so enables you to anticipate changes and handle them easily [Paige 2006]. A number of development methods such as SCRUM and test-first provide support for this strategy. The production method for a product line organization using this strategy provides tools that manage the multiple iterations and versions of products. The production plan describes how to identify, schedule, and integrate the increments of functionality. The production plan must provide guidance to developers on when to iterate and provide conflict resolution devices as the multiple threads of activity interact. This strategy is iterative and incremental at the level of individual assets.
4. **Be acquisitive.** Acquire as much of the software as possible [Bergey 2006]. This strategy affects the development of core assets more than their use. It subsumes the open source strategy and includes all strategies of acquisition including purchasing off-the-shelf software, as well as commissioning custom assets from an outside organization. The production method defines criteria for the various forms of acquisition as well as criteria for qualifying an outside asset for inclusion in the core asset base. The portion of the production plan related to development of the unique portion of a product directs product builders to search all available sources for the required assets.

5. **Be standard.** Seek out and use open standards. Participate in standards development so that you have maximum impact [Hoyer 2006]. This strategy constrains the development of core assets where there are applicable standards. The production strategy calls for assets to be designed to be compatible with standards defined in the domains of interest. This compatibility increases the possibility that the open source and acquisitive strategies will be successful in finding pre-existing implementations for specific assets. The production method describes a process for tracking the evolution of standards and techniques for integrating new versions of the standards. The production plan includes actions applying the test cases that accompany the standards, where available.
6. **Be automated.** Enable the engineers to carry out repetitive functions quickly and correctly. This strategy requires more up-front investment than more manual development strategies. Complex operations such as building the product can be repeated quickly and accurately [White 2007]. In this strategy, the information needed to build a product or to run tests is encoded to allow automatic execution of certain actions. Development information usually must be more constrained to ensure completeness and consistency. The production method defines activities in which assets are defined and maintained in machine-readable form. The production plan describes which tools product builders are to use for each of the product-building actions.
7. **Be generative.** Generate low-level artifacts such as source code and detailed documents from higher level models. This strategy moves maintenance and extensibility to a more general level [Czarnecki 2005]. A generative production strategy will result in a production method that defines a layer of model development and specifies a set of modeling tools and languages. The method spells out a sequence of transformations that begin with early models, proceeds through the architecture, and ends with compilable code. The product-specific production plan is at least partially generated from a template and the attached processes from other assets. In this strategy, modification of products and assets is managed through the modification of models rather than source code or documents.
8. **Be transformative.** Allow dissimilar data formats to be aligned. This strategy reduces the effort needed to write filters that glue tools together [McRitchie 2004]. A transformative production strategy results in a production method that uses a small number of meta-models, preferably one, as the basis for models of various kinds of development information. Transformations are constructed that create one model from another using meta-models and languages such as Query/View/Transformation (QVT) from the Object Management Group or the Active Template Library (ATL) from Microsoft. The production plan defines activities in which the product line models are transformed into the required product-specific models.

5.4 EVALUATING AND VERIFYING THE PRODUCTION STRATEGY

Rumelt describes the purpose of business strategy evaluation:

> *For many executives strategy evaluation is simply an appraisal of how well a business performs. Has it grown? Is the profit rate normal or better? If the answers to these questions are affirmative, it is argued that the firm's strategy must be sound. Despite its unassailable simplicity, this line of reasoning misses the whole point of strategy—that the critical factors determining the quality of long-term results are often not directly observable or simply measured, and that by the time strategic opportunities or threats do directly affect operating results, it may well be too late for an effective response. Thus, strategy evaluation is an attempt to look beyond the obvious facts regarding the short-term health of a business and appraise instead those more fundamental factors and trends that govern success in the chosen field of endeavor [Rumelt 1999].*

Rumelt also provides four criteria for evaluating a business strategy that are applicable to a production strategy for a product line:

- consistency: The strategy must not suggest contradictory goals and actions.
- consonance: The strategy should create more value than it costs.
- advantage: The strategy should provide competitive advantage.
- feasibility: The strategy must be achievable with the resources available.

We now discuss each criterion in the context of the strategy formulation process outlined in Section 5.1 through 5.3. The production strategy formulation technique outlined above produces effective strategies as evidenced by

- consistency - Prioritizing the production qualities derived from the product line goals provides a basis for making decisions that resolve inconsistencies among the elements of the strategy. Using Porter's model produces actions that are intended to resolve each of the forces. These actions, which will become the basis for the production method, are examined and conflicts resolved based on the impacts on the product qualities. The prioritization of the production qualities and the integration of their associated strategic actions into a complete strategy ensure that no contradictions are introduced.
- consonance - Serving as a bridge between the business goals and the production method, the production strategy provides great value. It ensures that the production method will initially meet the needs of the product line organization and provides a mechanism by which the method can evolve in concert with the business goals. A good way to evaluate consonance is to attempt to create a mapping between the production scenarios and the production strategy. If such a mapping can be created, the strategy is consonant with the intended uses described in the scenarios.
- advantage - Many organizations waste time and resources on producing products because they do not carefully coordinate how products are produced. The economies resulting from production planning bring an advantage that can be used in many ways, such as in reducing prices or in rapidly delivering products. Formulating the strategy is the beginning of a value chain in which the production strategy informs the production method, which, in turn, results in a production plan that is closely aligned with the business goals of the product line. This chain cuts across the organizational management, technical management, and software engi-

neering dimensions of the organization. The chain defines a conduit through which feedback, repairs, and evolutionary changes can be passed effectively.

- feasibility - The strategic actions that constitute the strategy cannot require more resources than have been budgeted for. Further, there needs to be a balance among the five forces so that no one force consumes a majority of the available resources. Feasibility can be judged by determining the impact of the change needed to implement the strategy. For example, an organization that has what it believes is a successful reuse program will probably not be able to immediately see a 50% increase in its reuse rate. An organization with no previous reuse experience may well be able to achieve large gains initially with these increases tapering off as more of the available methods are used.

6 An Example

This example of production strategy formulation features a fictitious company, Arcade Game Maker (AGM) that wants to adopt a product line approach to achieve its business goals. AGM, a subsidiary of a multinational corporation, produces a series of software-intensive products delivered directly to retailers that, in turn, sell them directly to individual consumers. The company is one of several subsidiaries that share portions of the product roadmap established by the parent corporation. They all make similar products but for somewhat different markets [SEI 2008].

The AGM product line is a set of video games. A comprehensive set of core and product-specific assets has been developed for use as a full-scale sample product line.[2] In this section, we present an example of production strategy development for AGM.

The AGM organization is adopting the software product line approach to product development. As part of its adoption strategy, the organization has decided to take an incremental approach to rolling out the core assets and products. The first increment will be a set of open source implementations of the games that will be made available for download. Succeeding increments will expand the feature set and the possible variations. The question now is what production techniques will help AGM meet its goals.

6.1 DEFINE PRODUCTION SCENARIOS

AGM is currently a traditional software vendor and the first products will be built using the Rational Unified Process (RUP), albeit modified for product lines. Management hopes that the product line approach will result in a simplified form of development in later increments. Two scenarios, shown in Table 4 and Table 5 , describe the initial and eventual situations, respectively.

Table 4: Initial Production Scenario

Stimulus	A game is requested in the early days of the product line.
Source of stimulus	A request comes from the marketing VP for one of AGM's largest markets.
Environment	Product building has just begun, and the core assets have not had time to mature.
Artifact	The requested game and modified core assets are the outputs of this effort.
Response	The game is available for deployment.
Response Measure	The game is available in less than two weeks from time of request.

Table 5: Product Line Production Scenario

Stimulus	A game is requested after the product line organization has matured.
Source of stimulus	A request comes from the marketing VP for one of AGM's largest markets.
Environment	Product building has become routine.
Artifact	new game
Response	The game is deployed on the new platform.
Response Measure	The new game is deployed in less than two days from time of request.

[2] The core assets mentioned in this example are available at http://www.sei.cmu.edu/productlines/ppl.

The production strategy should also handle the anticipated variations and modifications. The scenario about porting to a new platform, shown in Table 6, will represent several other possible variations.

Table 6: Portability Scenario

Stimulus	A requested game requires a new build for a new platform.
Source of stimulus	A product builder requests a new build.
Environment	Product building has become routine.
Artifact	requested game and new or modified assets for new platform
Response	The game is deployed on the new platform.
Response Measure	The game is deployed on the new platform in less than five days from time of request.

6.2 IDENTIFY THE CRITICAL FACTORS

AGM performed an initial iteration of the What to Build pattern and identified the critical factors found in Table 7.

Table 7: AGM's Critical Factors

Practice Area	Critical Factors
Market analysis	The specialized nature of the mobile platforms requires that products be compatible with a larger infrastructure. Some platform manufacturers provide software development kits for their products.
Building a business case	The need to provide the freeware products in time for them to affect the number of people who purchase the mobile device products.
Scoping	The AGM products only require static binding times. Customizable features are handled by a standard configuration file.
Technology forecasting	The forecasts for changes in mobile platforms identify areas that must remain flexible.
Understanding relevant domains	The domain is so widely understood that using domain-specific languages decreases the learning curve for new staff.

AGM's business case lists four strategic objectives that are an important input into the technique for developing a production strategy. The production strategy should address any of these that can be affected by how products are produced.

1. **Become a market leader:** Currently two other companies have a larger market share. This market is sensitive to how rapidly new technologies are introduced into products and the scope of the feature set. The company has been a "late adopter" of new technologies such as C++ and Java. To achieve its strategic objective, the company decided it at least must become an early adopter [Moore 2002].

   Factor to consider: Typically, an economist sees the demand for a product increasing as the price is reduced. So using the "differentiation" generic strategy should improve AGM's po-

sition in the market. Specifically, how can AGM get a broader array of products into the market more rapidly?

2. **Reduce time to market:** AGM will be able to produce products at an increasingly rapid rate. Ideas for games come from a number of sources. Many ideas come from the popular media where an idea has a very short lifespan. AGM must be quick to develop and deploy any games based on the popularity of a media or sports figure or one inspired by an actual event.

   Factor to consider: By introducing products more rapidly, AGM intends to capture the early adopters who are often influential in the user community. How can AGM reduce the time it takes to produce a product? Perhaps by exploiting the commonality among games, AGM can standardize and generalize.

3. **Increase productivity:** AGM will increase productivity so that the labor content per product decreases. Software makes up roughly 90% of the content of current products. To remain competitive, AGM must reduce the cost of building the games.

   Factor to consider: By getting more production from each worker, AGM would be able to adopt a lower cost strategy. How can more features be delivered per engineer hour? Perhaps raising the level of abstraction at which engineers work would allow them to produce output that can be transformed into concrete assets.

4. **Enable mass customization of products:** AGM will be able to serve more specialty markets. The current product development process requires too many resources to make products with projected sales of under a million units profitable. The parent company's marketing division sees an opportunity in the area of convention giveaway products. It would like to be able to add a company's logo and other advertising marks to a game and sell it to that company as a marketing handout at conventions.

   Factor to consider: AGM wishes to differentiate itself from other game manufacturers who either have a fixed set of games or a fixed set of parameters that can be adjusted at installation time. AGM wishes to provide specific types of customization to create different products based on customer requests. At what points in the development process should variations be bound? Perhaps through evolution, AGM can incrementally approach the level of customization it would like to achieve.

6.3 FORMULATE THE PRODUCTION STRATEGY

AGM specifically considered the critical factors in the context of the five competitive forces identified by Porter. The forces must be countered by either one of the generic strategies discussed previously or one of the more specific production strategies listed in Section 5.3. Table 8 shows AGM's approach to resolving each force.

Table 8: AGM's Strategic Actions

Force Name	Porter definition	AGM's Strategic Action
Substitutes	a currently available product or service that could be used in place of yours	Using a "lower cost" strategy early, made possible by reuse of legacy assets, will discourage our customers from switching vendors. Later, a differentiation strategy that takes advantage of the increased ability to customize will keep customers from switching.
Potential entrants	a product or service that might become available to be used in place of yours	By carefully mining legacy assets, AGM will take advantage of its extensive domain knowledge to more quickly produce accurate implementations. This will raise the cost of entrance into the market for any organization not currently in the market. These assets can help AGM become automated more rapidly.
Buyers	those who are currently purchasing your product or service	The business strategists have decided to have an initial increment of products that are free with later increments having more features at a higher cost. AGM will continue development in the same manner in the short term while developing a basis for cheaper, quicker production in the future.
Suppliers	those who provide some portion of the content of your product or service	In organizing and managing a group of products, AGM has increased leverage with suppliers. By being standardized, its production process will allow AGM to switch suppliers more easily to obtain better prices or faster delivery. By being acquisitive, AGM can obtain what it needs as cheaply as possible.
Competition	those organizations that are addressing the same market need or mission as yours	Through proper analysis of variation and selection of appropriate binding times for those variants, AGM can incrementally introduce additional features.

The strategic actions are then synthesized into actionable statements that constitute AGM's production strategy:

> *We will produce the initial products using a traditional iterative, incremental development process that uses a standard programming language, integrated development environment (IDE), and available libraries. We will create domain-based assets, including a product line architecture and software components, for the initial products in the product line in a manner that will support a migration to automatic generation of the second- and third-increment products.*

6.4 EVALUATE THE STRATEGY

Rumelt's criteria for strategy evaluation are the basis for the evaluation of the AGM strategy, as shown in Table 9.

Table 9 : Evaluation of AGM's Strategy

Criteria	Evaluation
Consistency	No contradictions have been found.
Consonance	Our production strategy results in a production system that encompasses a large number of possible products.
Advantage	The chosen production strategy is tightly aligned with the business goals, which gives us the advantage in executing our plans.
Feasibility	The strategy is realistic and relies on technologies that exist and will be sufficiently mature by the time we need them.

AGM applies these evaluative criteria as the strategy is developed, until a satisfactory strategy emerges.

7 Summary

Successful product production is the result of coordination between core asset and product development. The production strategy provides this coordination by defining a common direction rooted in the business goals and guided by the contrasting influences of the commonalities and variations among products.

A software product line is long-lived and encompasses the development of a group of similar products. As a result, strategic planning is more of a necessity than for projects that develop a single product at one point in time. A product line organization must consider how evolution of resources and techniques will affect product production over the lifetime of the product line.

The result of the strategic planning effort is an effective production system that can be evolved as the product line evolves. It can be evolved because of the traceability from the business goals to the techniques used to implement the strategies. It can be improved by the periodic evaluation of the measurable business goals.

A product line organization seeks to achieve specific strategic goals. Strategic planning of the production system is tied directly to the organization's goals. By explicitly defining strategic actions that address the forces on the product line, the organization is able to create a comprehensive strategy that is broadly based and includes the desired goals. This strategy is a sound basis for engineering the production method, which specifies in detail the technologies, models, and processes that will be used to produce products.

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13. ABSTRACT (MAXIMUM 200 WORDS)

Software product lines are of strategic importance to the organizations that adopt them, affecting both an organization's position in an existing market and its ability to react to new and changing markets. An organization's production system (i.e., how it builds its products) is also of strategic importance, directly affecting, for example, that organization's ability to deliver new products quickly (i.e., its time to market).

The production strategy for a software product line is the high-level description of how the production system realizes both the core assets and products. The production strategy is derived from the organization's business strategy and is intended to coordinate the actions of the core asset and product developers. The strategy describes how the product line practices should be employed so that the product line organization will achieve its production goals. This technical note describes a technique, which is based on well-known procedures for defining and evaluating a business strategy, for formulating the production strategy of a production system. An example of strategy creation is provided.

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