SAP Solution in Detail
SAP for Automotive

MANAGING PRODUCT CONFIGURATION IN A HIGH-VOLUME, MAKE-TO-ORDER ENVIRONMENT

Bringing Cost-Effective Flexibility to Automotive OEM Production Planning and Control Systems

CONTENTS

EXECUTIVE SUMMARY

In recent years, the automotive industry has faced an array of evolving and emerging challenges, from increasing globalization to the need to transition from production-driven push models to consumer-driven push/pull environments. Among the most fundamental challenges are the changing expectations of consumers who are increasingly interested in products that meet their specific needs rather than standard offerings.

To maintain profits and brand strength automotive companies must be able to quickly adapt to fluctuations in customer preferences by modifying both new and current products; ultimately, they must provide increasingly individualized products through make-to-order (MTO) manufacturing processes. They also need to shorten time to market for new products and innovations to support growth in existing, mature markets. And in today's hypercompetitive environment, they must do so while maintaining high levels of quality and competitive prices for small production runs.

While the need for such flexibility is clear, the practical realities of delivering it can be daunting. A shift to a rapid MTO environment increases the inherent complexity in automotive assembly. Each vehicle model consists of thousands of individual components that can be combined on demand, resulting in an immense amount of product and manufacturing data that must be managed – and that amount only grows with increasing product variety. This large number of product and model variations creates enormous complexity at the data level in the product development process. In short, the need to support product configuration in a high-volume, MTO environment is critical, and increasingly complicated and costly.

This paper explores how these issues can be addressed through a flexible, cost-effective MTO process based on the SAP for Automotive solution portfolio. This portfolio includes the SAP® Business Suite family of business applications and, in particular, the SAP ERP application in conjunction with the SAP Advanced Planning & Optimization (SAP APO) component of the SAP Supply Chain Management (SAP SCM) application.

This paper presents a flexible product planning and control process – or scenario – that can enable OEMs to effectively manage the MTO environment without creating excessive complexity and costs. The discussion begins with an overview of the MTO environment and the concept of variant configuration, and then examines the stages of automobile manufacturing from product configuration and planning through production and financial settlement. In particular, it looks at how SAP software can be used in three key areas of the manufacturing process: product development and production process design, production planning and scheduling, and production execution and control, as follows:

- **Product development and production process design**
  - Integrated product and process engineering (iPPE), a platform that enables the collection of all the data for an entire product life cycle in one integrated model
  - Product variant structure (PVS), which provides a product model instead of a standard bill of material (BOM). The PVS is a so-called "super BOM."
  - Process structure (ACT), which contains all working activities together with their resources and assignments
  - Factory layout object (FLO), which is used to map the plant structure to outline the hierarchy of production lines and serves as basis for line balancing and heijunka (level) scheduling

- **Production planning and scheduling**
  - The core interface (CIF), which allows data exchange between SAP ERP and SAP APO by means of an integration model
  - The model mix planning (MMP) process, which creates a balanced production schedule in the medium- to long-term planning horizon
  - Sequencing, which is conducted in the short term to display, evaluate, and process the results of MMP, and which enables scheduling of final products to individual takts
  - Rapid planning matrix (RPM), which stores product-related data in system memory for SAP APO and is especially suited for the explosion of products with many variations that are produced in high volumes
- **Production execution and control**
  - The action handler, which is SAP software that triggers and controls the production process after all planning activities are finished
  - Backflush, the process of consuming components from inventory as production is reported; typically used in an environment with a high volume of orders for small order quantities
  - Production cost tracking, which allows companies to determine key figures, stock values, and work in progress at the time of goods receipts based on the confirmed quantities for components and activities, as well as on the status of the process as recorded in the enterprise resource planning (ERP) system
  - Postings, which support quantity-based valuation, that is, debits and credits in product cost collection

The approach to product configuration and the MTO process discussed in this paper has been developed over several years by SAP in collaboration with a number of automotive companies. As a result, it represents a practical approach – based on real-world experience – to addressing this fundamental industry issue. It provides a thorough solution that can help OEMs develop the flexibility and responsiveness to stay in step with changing customer requirements and cost-effectively meet the needs of individual customers – a key to staying competitive in a global industry.

Note: It is recommended that the reader have some familiarity with the MTO process and an understanding of the classification system and object dependencies used in SAP software, as well the modeling options available for configurable products and how objects – self-contained components containing data and procedures – are related to other data and programming elements in SAP software.

CUSTOMIZED MANUFACTURING IN THE AUTOMOTIVE INDUSTRY

Unprecedented changes have brought unprecedented challenges to OEMs in the automotive industry. In particular, companies have to contend with increasing customer sophistication and information access, as well as customer demand for flexibility. In this environment, innovation and flexibility are essential for success because customers want their vehicles delivered quickly, configured to their requirements, and with technology that is up-to-date.

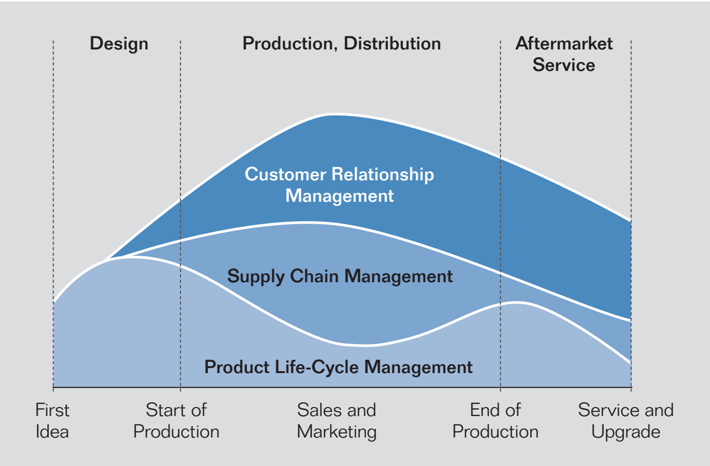

Figure 1: End-to-End Processes Drive Innovation and Fast Market Positioning

These challenges can be viewed in the context of the vehicle life cycle, beyond the manufacturing view. Different solutions are required as the vehicle moves through each stage of the life cycle (see Figure 1). In the early stages of design, product life-cycle management (PLM) is key. Supply chain management (SCM) becomes essential during the production phase, whereas customer relationship management (CRM) is important during the sales and aftersales phases. The scenario described in this paper focuses on the manufacturing of a configurable product, so it concerns SCM and, by extension, the SAP SCM application.

For OEMs, vehicle and component manufacturing contributes the greatest revenue in the automotive supply network, but it also offers the lowest profitability. This is especially true of vehicle assembly. Therefore, OEMs must work extremely hard to achieve reasonable returns.

The severe profit problems that many automotive OEMs suffer today, particularly in the United States, are closely related to huge rebates and sales incentives that they offer their dealers and customers for vehicles that are made to stock. In general, customers expect to receive a discounted price for popularly configured vehicles that only partly match their specific expectations and preferences. The resulting “incentives battle” between manufacturers can erode profits or force companies to take losses just to generate sales volume and preserve market share.

One possible solution is to manufacture vehicles based only on sales orders by using MTO production. However, simply producing standard vehicles that are sales-order dependent is not enough. In order to meet all customer requirements, vehicles must be configurable to an extent that meets customer requirements in an optimal way. Since most OEMs produce their cars in high volumes they need a reliable and fast production-planning solution that is capable of integrating rapid changes. More specifically, they need a production-planning and control system that includes an extensive variant configuration tool that can generate a product structure that is optimally and directly usable in production without extensive changes.

In addition, execution and control must be fast and flexible: the long-established techniques used to plan and control repetitive production are no longer sufficient.

The scenario described in this paper looks at the tools needed to fulfill these requirements, including SAP Business Suite, and especially SAP ERP, together with SAP APO, which is part of the SAP SCM application.

While this scenario focuses primarily on production planning and control, it is also plays a role in other areas of SCM and PLM. In fact, most of the tools used in this scenario are also employed in other phases of the product life cycle, including the development phase. The data used in this scenario must also be shared with several PLM processes – such as product development, production process design, and engineering change management (ECM) – in order for production overall to be effective. However, because the scenario focuses on the production phase, it is more-closely related to SCM than to PLM.

This paper's discussion of a flexible approach to product configuration and production planning and control begins with a look at MTO production, an outline of the system landscape that is required for MTO, and a discussion of variant configuration.

Product Development and Production Process Design

This section looks at the concept of integrated product and process engineering (iPPE) and the iPPE workbench in SAP software. It highlights the importance of consistent master data across the whole product life cycle including design and manufacturing application areas, while allowing for more customization. iPPE can help manufacturers design and balance production lines while improving upon the standard approach for modeling new product concepts and programs in manufacturing environments.

In iPPE, the product model is represented in the product variant structure (PVS) instead of a standard bill of material (BOM). The PVS, a so-called "super BOM," models a configurable vehicle with all its possible orderable and buildable combinations. The standard routing is replaced by the process structure – called ACT – that contains all working activities together with their resources and assignments. The plant structure is mapped by means of the factory layout object (FLO) that structures the hierarchy of production lines and serves as basis for line balancing and takt scheduling. The paper discusses how all the relationships between iPPE objects can be implemented in order to achieve a functional model of the production process. And it deals with how you can track changes through ECM.

Production Planning and Scheduling

This section looks at in-depth line balancing, model mix planning (MMP), and interactive sequencing, as well as the calculation of material requirements with the rapid planning matrix (RPM). Production planning and scheduling takes place in SAP APO through the exchange of data with SAP ERP via a core interface called CIF. In the MMP process, the optimal production sequence is calculated in daily buckets based on definable constraints. In conjunction with MMP functionality, advanced memory and data management technology is used to improve system performance by storing all relevant data in system memory. Meanwhile, interactive sequencing software displays, evaluates, and processes the results of MMP, providing the user with detailed information on, for example, start and end times for activities or the effect that variance characteristics have on planning. With interactive sequencing software, employees can modify a production sequence according to plant, customer or supplier requirements via the easy-to-use Drag&Relate™ feature from SAP.

The explosion of product and process structures and the calculation of requirements take place in the RPM – a product-related database object that is stored in system memory for SAP APO. The RPM is especially suited to the explosion of products that have many variations and are produced in high volumes. It enables users to perform fast subdaily calculations.

Production Execution and Control

This section looks at the manufacturing execution system (MES) and action handler software from SAP. Once planning activities are finished, the production process is triggered and controlled by action handler software, which not only enables the use of supply areas (for example, to integrate pull-oriented, lean practices such as kanban), but also lets users define action points or adopt them from the iPPE structure to perform tracing and backflush activities dependent on certain events. The software allows you to perform a two-step backflush, which separates controlling and financials postings from logistics postings in order to smooth system load. This section also covers cost settlement and cost controlling activities in depth, including variance calculation for product cost collectors, calculation of daily production costs, and analysis of work in progress (WIP).

Finally, this paper provides a brief look at the SAP xApp™ Manufacturing Integration and Intelligence (SAP xMII) composite application to support manufacturing execution in an automotive environment.

Characteristics of MTO Production

In MTO production, a product is produced specifically for an individual sales order. This approach is used when production planning is not required or not possible due to high variability. Demand management is not involved in this process, nor is there an allocation mechanism. Instead, orders are handled as they come in. Each product configuration is essentially unique, although the same or similar production processes are involved in the production of all vehicles. Because each product is manufactured specifically for an individual customer, finished products are rarely placed in stock.

Depending on how cost tracking is associated with MTO production, there are two ways to process MTO items during sales-order processing: using the sales order and using the project system. Only cost management using the sales order is considered in this paper.

Figure 2: Process Flow of the MTO Scenario

Figure 2 shows the complete process flow of MTO manufacturing, along with the scenario that is described in the following sections.

Prior to the release of the sales order to manufacturing, the vehicle has to be fully configured; this is done using the variant configuration approach described in the next section. Proper variant configuration and production environment schemes must already be set up.

All vehicles are produced exclusively to the corresponding sales-order stock so there is no anonymous stock keeping. Because no fixed product structure is required it doesn't matter whether the material has a BOM (for internal production) or is procured externally. However, the configurable vehicle in this scenario is produced in-house using a PVS instead of a BOM as product structure.

After the vehicle has been configured, production and MMP are carried out, followed by the actual monitored and controlled manufacturing process. As soon as the final vehicle is completed to sales-order stock, delivery and billing are carried out.

All of these phases are part of an MTO manufacturing process. However, the scenario described in this paper focuses solely on the setup of variant configuration and the production environment, production and MMP, and the execution and control of the manufacturing process.

Generation of the sales order, working with sales-order stocks, and delivery and billing of the finished vehicle are not part of this scenario. However, possible approaches to handling settlement of production costs are discussed.

VARIANT CONFIGURATION AND HIGH-VOLUME MTO WITH SAP FOR AUTOMOTIVE

Recommended System Landscape

To support the flexible MTO scenario described in this paper, companies should have SAP for Automotive with DIMP 4.71 and SAP SCM 4.1 (see Figures 3 and 4) or more recent software. Figure 4 shows an overview of the SAP Business Suite family of business applications, with SAP ERP and SAP SCM providing solutions and the SAP NetWeaver® platform providing the underlying infrastructure.

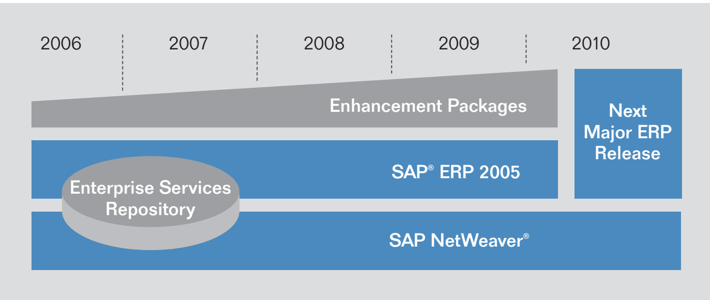

Figure 3: Development Road Map for SAP for Automotive Solutions

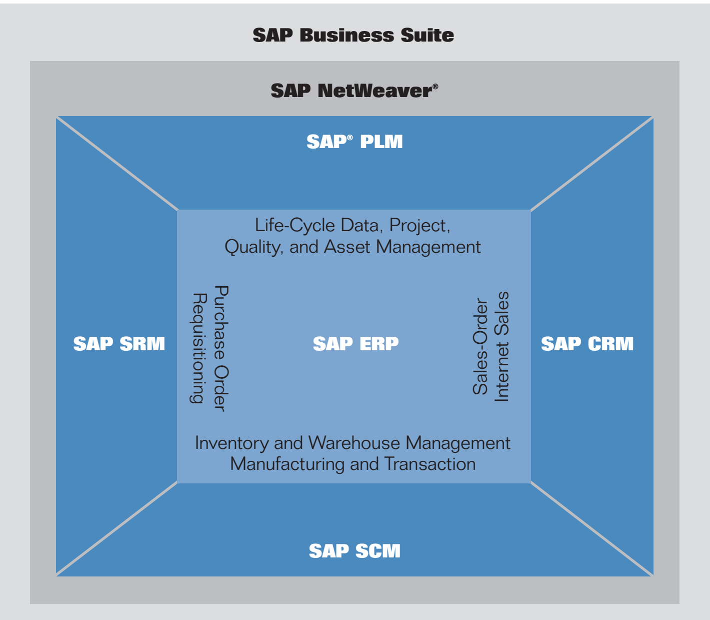

Figure 4: Components of SAP Business Suite

The flexible MTO scenario concentrates on variant configuration functions in SAP for Automotive as well as setup of the production environment using an iPPE workbench in SAP software, production planning and execution in SAP APO, and the final postings in SAP for Automotive, and cost settlements.

Figure 5 provides an overview of the MTO process.

Core SAP ERP software and SAP SCM, which includes SAP APO, work together in this scenario. Variant configuration of a vehicle and master data maintenance take place in core SAP ERP software. The functions described below are based on the assumption that the configuration takes place in a discrete industry (DIMP) software-based system with the iPPE workbench and configuration data that is transferred via a CIF interface to SAP SCM. CIF initialization is also done in the iPPE workbench.

At the start of MMP and sequencing, SAP APO receives the specific customer requirements from the sales order in SAP ERP and combines this configuration data with data that has already been transferred from the manufacturing environment. The explosion of the BOM – that is, the product variant structure – is created via the RPM, where only one BOM – a so-called super BOM – per configurable material is used. The order headers are directly transferred from the RPM to action handler software. Component requirements are derived from the RPM and transferred to the production planning component of SAP APO and SAP ERP to perform delivery scheduling and planning of the component materials.

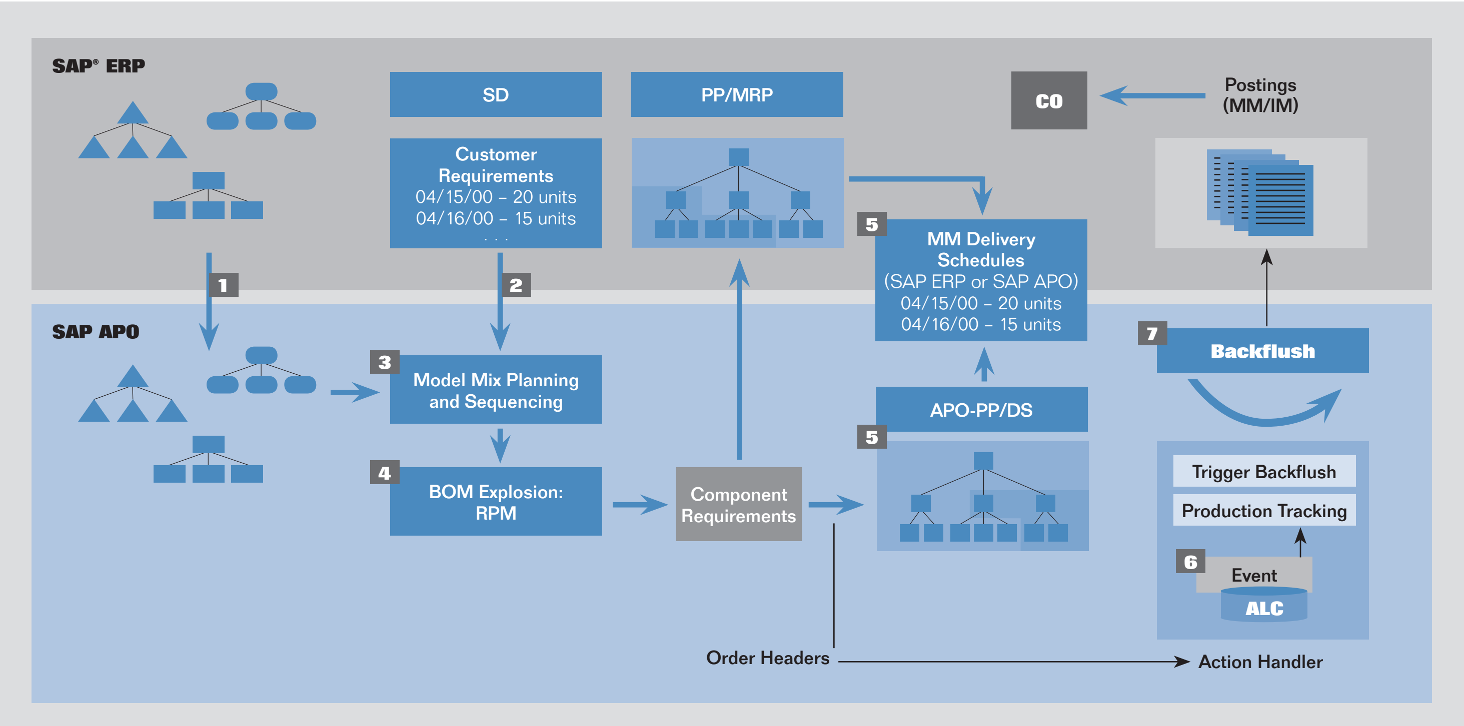

Figure 5: Process Overview

Production execution and control is taken over by action handler software, which is event-driven and handles production tracking and triggers the backflush process.

Finally, all appropriate data is transferred to SAP ERP for final postings used in material and inventory management and cost settlement in the controlling software.

Variant Configuration

Today, when dealer lots are crowded with a limited set of variants for each model, customers demand a price discount, leading to reduced margins for the vehicle dealer and significant reductions in the OEM's revenue – reductions that can negate the savings achieved by the optimization of the production process. Moreover, most major automotive OEMs are represented in many countries, and therefore need to consider local restrictions and market characteristics, such as EU tax advantages for cars with diesel engines equipped with a particulate filter. Local differences in cultural and social manners also need to be considered. For OEMs, being able to let customers configure their cars individually to a high degree is key to profitability and customer satisfaction.

Meanwhile, with a competitive and largely saturated market, customers expect high-quality products and are extremely price sensitive. Developing new vehicles that meet these expectations requires OEMs to take advantage of a variety of available technologies, sophisticated materials, and electronics, which can drive costs up. Thus, designing a basic vehicle platform that can be easily reconfigured for as many markets as possible will maximize the potential profitability of that vehicle over its life cycle.

Looking at the realities of a global, customer-driven industry, it is clear that manufacturers need a sophisticated variant configuration model to remain competitive. But the use of variant configuration has a tremendous impact on the whole supply chain, as customers look for vehicles that closely match their expectations, and as OEMs pursue more and more innovations to include in vehicles. Because the ability to respond to changing global demand is very important, manufacturers must also be able to quickly set up infrastructures whenever and wherever they are needed. As they emphasize adaptability, individualization and innovation, OEMs must also focus on the reduction of both operational costs and implementation time.

These business requirements make tremendous demands on the IT systems involved. Those systems need to have comprehensive capabilities for collaboration, scalability and adaptability, and evolution. Collaboration in this case means support for industry-specific processes as well as the integration of different systems throughout the supply chain. Scalability and adaptability mean having the ability to provide multicountry support and to enable the vertical and horizontal growth of the IT landscape. Evolution means enabling continuous changes in a flexible way, as well as efficiently adjusting to new business processes and tasks.

Meanwhile, to achieve low total cost of ownership (TCO), it is important to reduce the number of internal systems – ideally, one system with several components that share a common database. This single system must offer high levels of real-time availability, with downtime reduced to a minimum. It must enable companies to manage today's high variability and shorter development cycles. It must help ensure data consistency, especially in product and process engineering and manufacturing systems. And it must provide greater information transparency – internally and through all parties in the entire value chain, to support accurate inventory management.

These factors add up to several key requirements for a solution: the infrastructure should be designed for scalability and high volumes, and the overall platform should integrate product and process engineering. Optimized material flow and a seamless connection to internal and external suppliers are also important.

Table 1 provides an overview of what SAP for Automotive solutions offer in the area of high-volume manufacturing.

	SAP® SOLUTION
Planning and Execution	Offers planning and execution functionality simultaneously in a 24x7 manufacturing environment
High Availability	Offers a high-availability (24x7) solution that is robust and withstands disturbances
Real-Time Processing	Offers extremely high timeliness with near real-time planning when based on extremely fast material requirements planning, optimal processing, and real-time scheduling and updating of assembly activities and assembly components
Master Data	Provides a secure consistent master data framework for robust manufacturing processes with a complete description of the assembly net plan, which exactly maps the manufacturing processes
Mass Data Processing	Employs a hybrid database system (enhanced MaxDB) to process enormous volumes of information with speed and accuracy

Table 1: SAP for Automotive in High-Volume MTO

The solution discussed in this paper is designed for high-volume manufacturing processes in the automotive industry, and can meet the demands of various industry business processes, such as final assembly, powertrain or components manufacturing, and subassembly.

Variant Configuration in the SAP Software Environment

It is clear that variant configuration can play an essential role in the automotive environment. However, companies also need to manage the tremendous complexity in sales and production processes created by the number of options and features involved. These processes must be performed quickly and accurately, and keep pace in a world in which product life cycles are declining and development cycles are becoming longer and more complex.

Using SAP Classes with Variant Configuration

In the SAP software environment, configurable material is defined as a product that can be produced in multiple variants. The configurable material is not a finished product itself, but rather a potential product that covers all possible features of the realized variant. These features are described in SAP ERP using "characteristics." However, these features are not directly applied to the product. Instead, classes are used. Therefore it is important to understand the classification system in SAP ERP, which is also used for the maintenance of master data.

Classification is used widely in SAP ERP. It is possible to classify nearly every type of master data in the software; different types of master data can be assigned to different class types (for example, 010 for vendors and 019 for work centers, respectively). Material masters can use several class types, with each type serving a unique purpose. Variant configuration requires the class type 300 with class-type specific control parameters, screen sequences, class statuses, and so on. The scenario described in this paper assumes that at least one product class has been created for the vehicle that is being configured. It is also possible to arrange several classes in a product-class hierarchy (for example, if the same car, more or less, is produced for different countries).

You can create classes using the SAP software menu or directly via the transaction *CL02* and maintain them by using several tab screens. Table 2 provides an overview of the mandatory and optional possibilities of class maintenance. As shown in the table, only the *Basic Data* and *Characteristics* screens must contain data. Characteristics are used to define the attributes of the configurable product, such as engine or exterior color.

SCREEN	DESCRIPTION	REQUIRED/ OPTIONAL
Basic Data	General information and control data	Required
Keywords	Strings for finding the class by the search help function (F4)	Optional
Characteristics	Characteristics of the class	Required
Texts	Texts explaining the class	Optional
Document	Existing documents for this class in the document management system (DMS)	Optional
Standards Data	Data for standardized classes (for example, DIN standards)	Optional
Additional Data	Additional data for class nodes	Optional

Table 2: Required and Optional Class Screens

The characteristics themselves comprise several screens, whereas *Basic Data* and *Values* are mandatory screens (see Table 3). The specific data type of a characteristic (for example, a numeric or character value, a date, or a user-specific data type) is specified in the *Basic Data* screen together with its length and whether or not its assignment is required. For the data types, several values are definable. A set of constant values for the data type "character" (CHAR) is possible, as are intervals for numerical data types or combinations thereof. You can also maintain additional values and define the number of simultaneously selectable options (single, multiple, or restricted values).

SCREEN	DESCRIPTION	REQUIRED/ OPTIONAL
Basic Data	Description, format, control data	Required
Description	Multilingual headings and descriptions	Optional
Values	List of all possible or required characteristic values	Required
Additional Data	Reference characteristics/linked documents (DMS) characteristic display for value assignment	Optional
Restrictions	Restrictions to class types	Optional
Go to Classification	Classification of characteristic	Optional

Table 3: Characteristic Screens

After you define a characteristic, you need to assign it to a specific class in SAP ERP. Then you assign that specific class to the configurable material in the classification view. The configurable material thus adopts the characteristics assigned to the specific class. It is possible to assign one class to different configurable materials.

Using characteristics in configurable materials via classes enables customers to configure their product individually by using these characteristics. One customer may prefer a red station wagon model of a car with a V6 engine and automatic transmission, while another customer may prefer a blue sport version with a turbo engine and manual sport transmission. These two vehicles would use completely different sets of characteristic values, but both would belong to the same configurable vehicle type and the same product class.

Products don't have to be fully configurable. You can define a partially configurable product for which the customer must accept characteristics with certain values, or to allow the customer to select only predefined packages or to combine only certain characteristics. With a fully configurable product, only one material master has to be maintained, while several material masters are needed for partially configurable products and nonconfigurable products.

It is important to know how to model characteristics in the most efficient way. Instead of maintaining one characteristic with all possible values, it is far more efficient to maintain one characteristic for each attribute value, which is either enabled or not enabled. This approach helps you achieve higher levels of performance with the solution.

Consider the following example: You want to model the possible colors for a car's exterior. You can choose to define one characteristic as "color," with the possible colors as attribute values for this single characteristic. Or you can choose a better, more efficient way, that is, to model several characteristics – one for each possible color. Each of these characteristics would have only two possible attribute values: "yes" or "no." This means if the customer chooses a specific color, the value of the characteristic for that color would be yes, and the values of all other color characteristics would be no.

To summarize: In variant configuration, a class groups together the characteristics that describe a configurable material. These characteristics take effect during BOM and ACT explosions. Note that only classes of type 300 can be used for variant configuration. The indicator that allows configuration for a class type is set during customization of the classification system.

Configuration Profiles and Object Dependencies

You must create a configuration profile before sales orders can be entered. This profile enables the inclusion of actions (for example, you must install a special battery in vehicles with air conditioning) and constraints (for example, you cannot equip a convertible with a sunroof). If the configuration profile contains the appropriate settings, you can make manual changes to the BOM or product structure for a sales order (for example, to delete or insert components). The configuration profile completes the connection between the material and the variant class.

Configuration profiles can also be used to assign and maintain object dependencies. Object dependencies are used to define the interdependencies between characteristics and characteristic values (for example, the values allowed for the interior color of a vehicle might depend on the value selected for the exterior color). These dependencies control which components are selected from a BOM and which operations are selected from a task list. To define dependencies, special syntax must be used in the dependency editor.

You can define global and local dependencies. Global dependencies are created centrally and can be assigned to several objects, while local dependencies are created for one object and can only be used with that object. Configuration profiles can also contain different pricing rules (for example, whether or not the customer has to pay an extra charge for an engine with more horsepower).

There are many different types of object dependencies and each type has a slightly different function. Object dependencies are assigned different types of master data, such as BOMs and routings. The type of master data restricts the types of object dependencies that can be assigned.

Table 4 provides an overview of the most common object dependencies. This paper primarily addresses local dependencies as selection conditions, because they are essential for a configurable product.

OBJECT DEPENDENCY	DESCRIPTION
Precondition	A precondition provides dynamic control of characteristics and values. A precondition can be used to hide characteristics values that are not allowed and thereby ensure that the configuration of an object is consistent. A precondition contains the definition of the circumstances under which a characteristic or value is hidden. Note: It is also possible to use restrictive characteristics to restrict the allowed values of characteristics when an object is configured. A precondition is fulfilled if the condition entered is either true or not violated. A precondition is not fulfilled if a different value is selected for the specified characteristic.
Selection Condition	A selection condition provides dynamic control of characteristics. A selection condition ensures that all the objects relevant to a variant are selected. It determines which variants require a specific component or operation and when it is mandatory to assign a value to a characteristic. A selection condition is fulfilled if the condition in it is unambiguously true, if the value in the condition is set for the characteristic. A selection condition is not fulfilled if a different value or no value is set for the characteristic.
Procedure	A procedure offers inference of characteristic values with the option of overwriting and recursive calculations. A procedure can infer values for characteristics; it displaces obsolete "actions." A procedure can overwrite default values that are set by other procedures and can also set default values for a characteristic that can be overwritten by the user. If several procedures are assigned to an object a processing sequence can be defined.
Constraints	A constraint offers dynamic control of characteristics and characteristic values. This dependency type is mainly for intensively interactive configuration tasks and for configuration tasks in which dependencies between the characteristics of several objects must be taken into account. The main purpose of a constraint is to monitor the consistency of a configuration. Constraints have the following distinguishing features: ▪ Constraints can be used to describe the dependencies between completely different objects and their characteristics. They store information on which conditions must be fulfilled if the configuration is to be consistent. ▪ Constraints are not directly allocated to individual objects. They are grouped together to form dependency nets and allocated to a configurable material in the configuration profile. ▪ Objects are entered in constraints in their general form of expression. As a rule, reference to objects in constraints is achieved by entering the class to which the objects are allocated. ▪ Constraints are declarative dependencies. The processing sequence of constraints and the point in time when constraints are processed are not relevant. ▪ Constraints are not processed in a specific order. It cannot be determined when a specific constraint is used. In any processing situation a constraint is only processed once. If a value that is relevant to the constraint is changed, the constraint is triggered again.

Table 4: Common Object Dependencies

Selection conditions are mainly used in BOMs, while constraints are used to validate the sales order.

In the scenario described here, the software generates a production order based on a demand source – in this case, a sales order. To determine which components are required, the software explodes the BOM; in this scenario, it is one super BOM with all possible components. Selection conditions are used to determine which components should be selected from the super BOM. Selection conditions are based on characteristic values. The basic syntax is "Pick this part if (characteristic = x . . .)." However, you cannot use selection conditions to validate combinations of characteristics; instead, you can use constraints to accomplish this. You can enter selection conditions in the super BOM to determine which components are used in a certain order. For example, selection conditions define when a certain type of engine has to be used.

From release DIMP 4.7 on, SAP software includes an extended dependency editor. Previously, selection conditions could only be entered by typing the syntax logic. While this option is still supported, you can now enter and maintain the same logic by pointing and clicking.

You can use constraints to ensure that the options selected by a customer are valid. You can set them to automatically determine specific characteristic values (for example, one value of a characteristic can determine the value of other characteristics in an equipment package). Or you can use them to prevent the selection of other characteristic values (that is, one characteristic value restricts the selection of other characteristics). If a constraint is violated, the sales order cannot be saved. Once all constraints have been validated, the sales order can be saved and sent to the production planning software.

Modeling Options for a Configurable Product

Variant configuration is required for the modeling of a configurable BOM. The master data must be defined regardless of the BOM tool used.

There are several options for creating the configurable BOM:

- Use of standard production planning BOMs and routings in SAP ERP
- Use of the iPPE PVS, discussed in detail in this paper
- Use of a BOM kept in a legacy system for which interfaces to SAP ERP have to be built

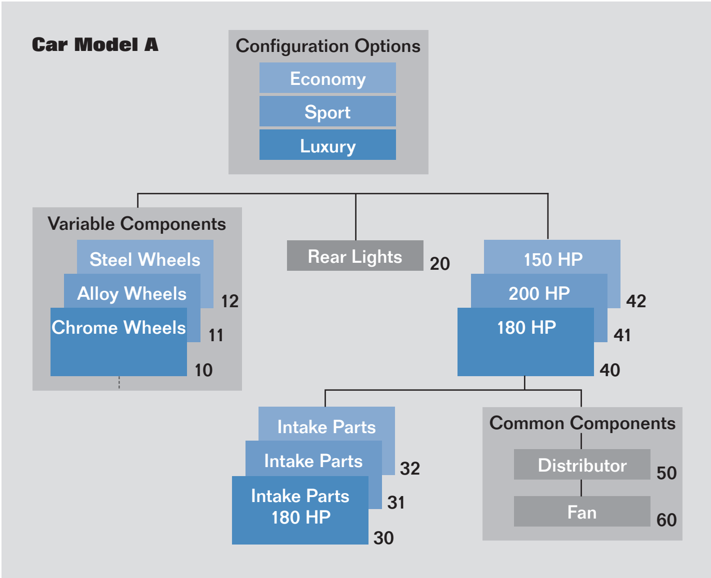

Figure 6: A Super BOM in SAP® ERP

Figures 6 and 7 show examples of a super BOM and super routing in SAP ERP. In this case, it is a standard configurable ERP BOM. As mentioned above, it is sometimes called a super BOM because it includes all of the possible components of a configurable product within one BOM structure. The variable components have items in the BOM, but are not related to each other. If the dependencies used to select each component are incorrectly maintained, it will be difficult to detect and resolve errors that may lead to serious problems later in the production process. For example, the result could be that two sets of wheels (chrome and alloy) are ordered when only one is actually needed. Common components in the standard BOM will be chosen regardless of which options are used in configuration – they don't possess any object dependencies.

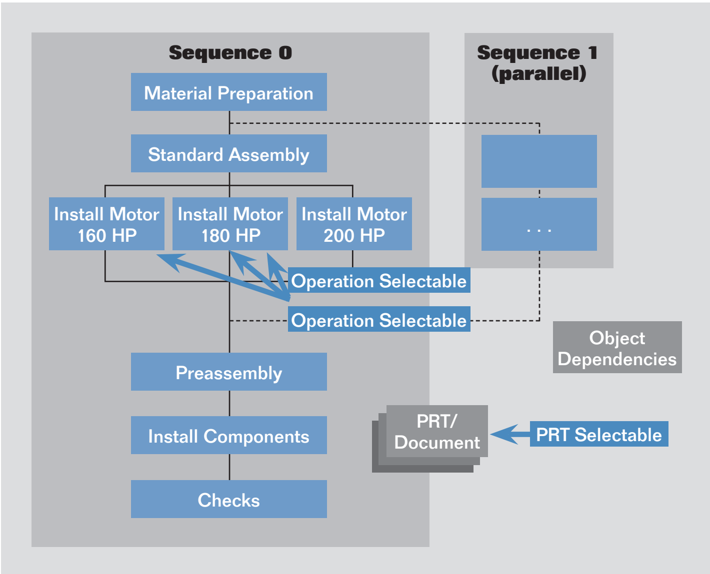

Figure 7: Super Routing in SAP® ERP

The routing of a configurable material includes a master sequence and can also include parallel and alternative sequences. In addition, it can encompass operations that can include sub-operations and that can contain assignments to production resources tools (PRTs) at the operation and suboperation levels.

Sequences (apart from the master sequence), operations, sub-operations, and PRT assignments can be optional, based on the object dependencies assigned to these objects. These routing objects can be selected and used based on the component variants that are chosen from the BOM.

Figure 8 shows a comparison between the core BOM and iPPE, both with configuration. In the core BOM configuration on the left side, the material master is the central data element required for production. The material is linked to the BOM, routing, and configuration profile. The configuration profile allows for assignment of procedures and constraints, which can be applied during the configuration of the product.

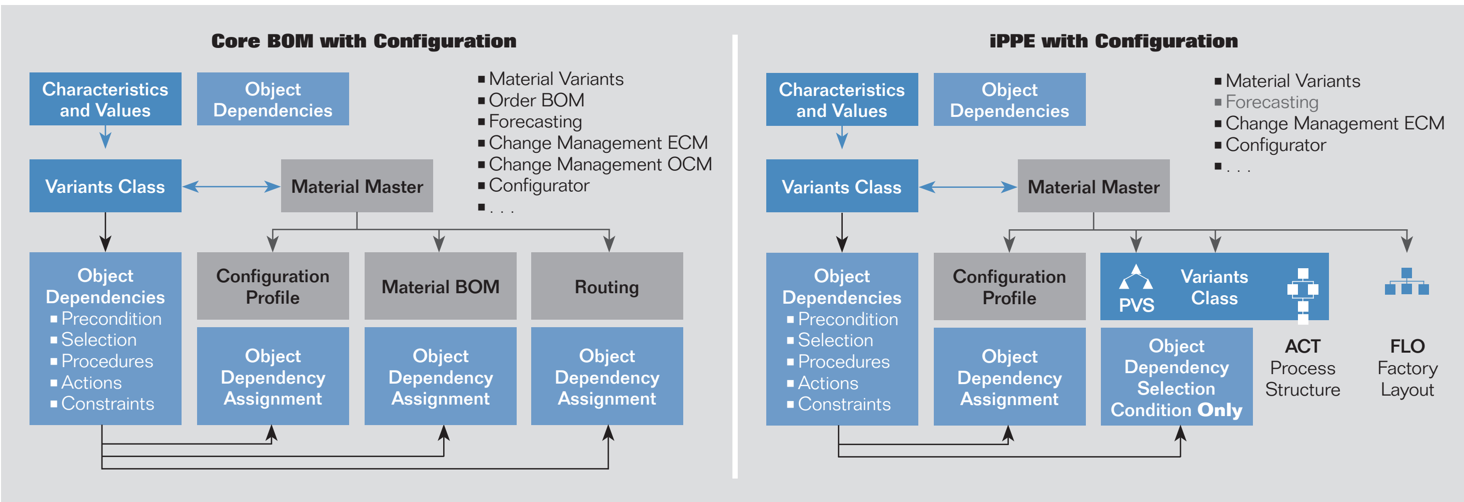

Figure 8: Comparison Between ERP Standard and iPPE

In an iPPE environment, the BOM and the routings are replaced with iPPE structures. The configuration profile (with the procedures, constraints, and so on) of an iPPE structure does not differ from the standard BOM. The material master is the key element for variant configuration in an iPPE environment. The process of assigning the configuration profile, class, characteristics, and object dependencies is identical to that used in the standard ERP variant configuration.

The different master data elements are the iPPE elements maintained in the production version. This includes the PVS, ACT, and FLO. With iPPE, only the PVS has object dependencies and only selection conditions are possible.

Comparing these two methods, it is evident that the iPPE workbench can only handle the iPPE PVS with configurable materials or an iPPE assembly BOM with no variants (that is, with fixed rather than configurable relationships that are, for example, important for the visualization of subassemblies and for the integration of other tools found in iPPE, such as engineering and PLM functions). The iPPE workbench cannot use standard ERP BOMs. The same issues apply to the execution of subdaily planning, planning in SAP APO, and planning in discrete industries. It is only possible to use Drag&Relate with iPPE; likewise, material requirements planning (MRP) with the RPM is only possible when you use the iPPE PVS.

Functionality for planning for other industries with iPPE is also available.

You must use the standard ERP BOM if you plan to use standard ERP functions.

The choice of modeling option also depends on manufacturing criteria and the project in question. iPPE is more advantageous than the standard ERP BOM when there are high volumes, many logical structure relationships, advanced scheduling in SAP APO, collaboration, and of course, highly configurable products.

If the basic functionality in SAP ERP will be used and integration is preferred, using the standard ERP BOM together with variant configuration and SAP APO is recommended. Standard SAP ERP functions include Drag&Relate, which is not as sophisticated as some features in iPPE.

USING IPPE

As mentioned earlier, iPPE stands for integrated product and process engineering, and represents a platform that enables the collection of all the data for an entire product life cycle in one integrated model. It is particularly suited to products with many variants. As such, it is much more than just a tool for building a super BOM, as discussed in the previous section (see Figure 9).

iPPE can be used to document data, and later reuse and update it starting in the early phases of the research and development process for a product. A complete production model can be presented because iPPE lets companies store master data for BOMs, routings, and line design in one model. iPPE is particularly suited to repetitive manufacturing, including production with variants in individual sales orders (see Figure 10). While this paper focuses on the manufacturing phase of the product life cycle and the production applications of iPPE, the iPPE approach can also be used, for example, as an early engineering tool; it supports complex engineering processes such as the concurrent engineering of product structure and process information that is used in simultaneous engineering. The data is maintained in a functional structure, which is filled with additional data at later stages in product development and production, and ultimately covers the whole product life cycle.

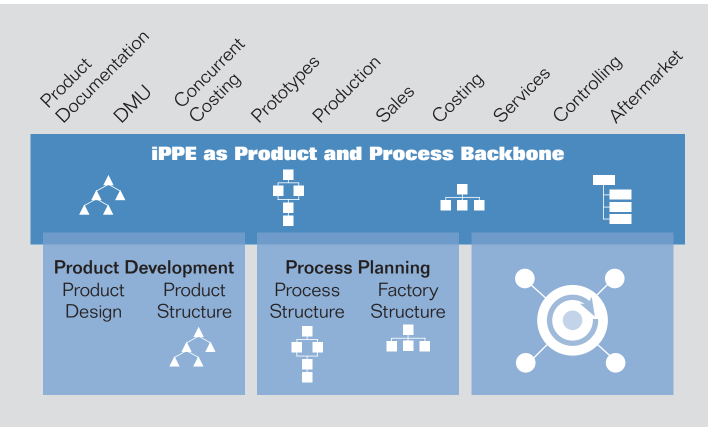

Figure 9: iPPE–Supporting the Entire Life Cycle

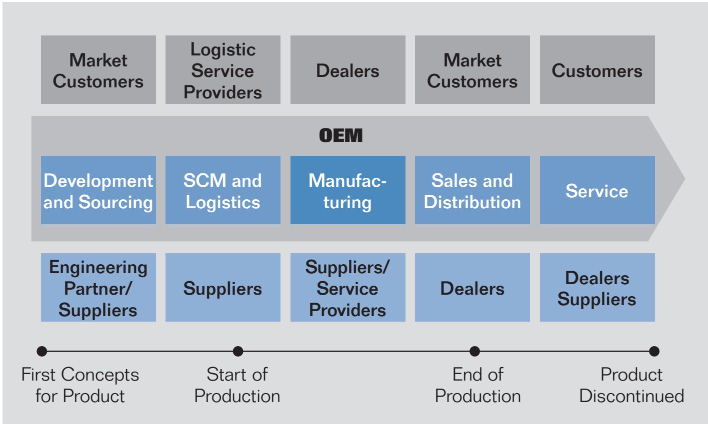

Figure 10: Common Master Data Model for All Solution Areas

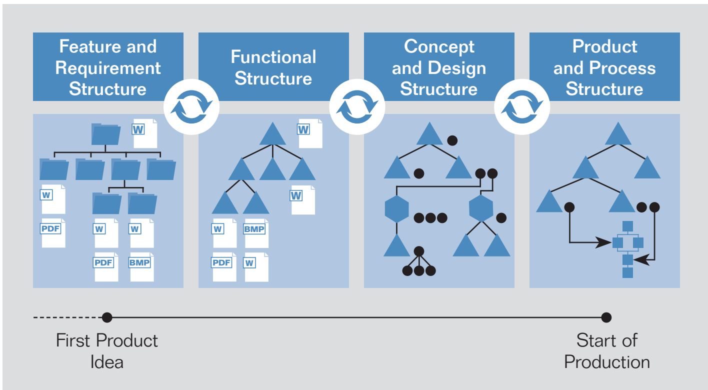

Figure 11: iPPE–From Design Requirements to Production

iPPE encompasses several phases that extend from the first product idea to the start of production, as shown in the accompanying figures. The feature and requirement structure contains documents of features and requirements of the product as well as assignments to the following two phases: functional structure and concept and design structure. The functional structure represents the first structuring of the product that may contain no material masters and only a few concept ideas. All the various alternatives of the product concept can be included in the concept and design structure. The final concept alternative of this structure has to be released to the product structure. The product and process structure contains the final concept alternatives and the appropriate manufacturing information.

iPPE constitutes a strategic development direction for SAP software, and SAP is committed to continuing development in this area. Currently, iPPE is supported by the following SAP products:

- DIMP add-on (for example, the IS-automotive solution)
- SAP NetWeaver Master Data Management component
- the SAP SCM application, which includes SAP APO
- SAP Business Suite

Generally, SAP components that handle the following are required for iPPE:

- ECM
- Classification system
- Variant configuration

It should be noted that not all iPPE object types are available in every software offering and that iPPE is not used the same way in all software. Also, the functionality available in one client may not be found in another client.

It is essential to install the software necessary for iPPE and to properly maintain the data in order to plan material requirements with the RPM.

The iPPE Workbench

To support iPPE, SAP software includes an iPPE workbench. The data modeled in the iPPE workbench can be divided into three areas: PVS, process structure (ACT), and line design of FLOs. These areas will be explored in the following sections.

The User Interface

The integrated handling of components, activities and operations, and lines and resources in the iPPE workbench enables a standardized look and feel. However, role-specific user views are still possible. Furthermore, the iPPE workbench features Drag&Relate functionality as well as comprehensive navigation functionalities. Several options are available for visualization tools, including an enterprise application integration (EAI) viewer, network graphics, and the possibility of including small applications such as those for a work list or personal favorites.

The iPPE workbench screen in SAP software includes a number of features. In the menu bar, users can access several applications and reports, including visualization tools. An application toolbar lets users load, change, and create several objects via the load area, as well access several filters. If the filters are set to active, it is possible to define and store different types of filters so these values can easily be retrieved. The filters constrain the view of certain objects by using parameters. With filters, one can set up configuration simulations as well as ECM parameters and display parameters (object types and values).

In the load area, existing objects can be displayed or changed. It is also possible to search for certain objects by entering the node name, the class, or the class type. All fields are optional, so if an iPPE object has no class, the corresponding field can be left blank.

Users can also create new objects in the load area by clicking the *Create* button. The type of the new node depends on the assigned application; every application has its own node types.

The following table provides an overview of the different application types. PLM objects are master data elements that can be loaded into the iPPE workbench for viewing certain information, such as lists of the characteristics used or the details and properties of the corresponding object.

APPLICATION	APPLICATION TYPES	
CMP – Product Structure	PVS	Access Node
		View
		Structure Node
	Color Node	
	Assembly	Assembly Group
		Variant Assembly Component Node
	Focus Nodes	For PVS
		For Assembly
		For Color
ACT – Process Structure	Routing Header	
	Grouping Activity	
	Operation	
	Activity	
FLO – Factory Layout	Line Network	
	Line Area/Alternative Line Group	
	Line Buffer	
	Line Segment/Intermediate Buffer	
	Work Package	
	Worker	
	Operating Facilities	
	Planning Resource	
COL – Color Scheme		
FOC – Focus		
RES – Production Resource		
SET – SET Documentation		
PLM Environment	Change Number	
	Classification	Class
		Characteristic
	Document	
	Focus	
	Material/Product	
	Project System	Work Breakdown Structure (WBS) Element
		PS Operation
	Engineering Node	

Table 5: iPPE Workbench Object Types

The application trees and lists are displayed on the user's screen. They allow you to view the hierarchical object structure and the relationship among the node objects – for example, to determine the completeness of the data. Existing nodes can be opened or expanded and contracted to display them or change the activities. By default, a super BOM with all possible nodes and values is displayed. You can also use Drag&Relate among these structures if you have included this feature during customization. You can review the node object hierarchy and changes by dragging and dropping node objects. You can even store favorite objects in the "stack" – which is similar to a Web browser "favorites list" – for quick recall.

The screen also displays all object data details in spreadsheet format indexed by tabs, enabling the maintenance of important data. Table data can be ordered, changed or adopted, printed, or saved as external files.

Furthermore, the iPPE workbench offers additional functions and reports for data integration and consistency. To maintain relationships (for example, between the BOM and routings), users can open a second navigation window to easily perform Drag&Relate functions. The application window also offers a reporting functionality with several reports to ensure that all iPPE objects – including product and process assignments, line assignments, and line balance – have been related and integrated correctly. For example, it is possible to perform user-defined status tracking such as master data completing.

While the workbench provides preconfigured status functionality, users can also freely configure statuses. Object data tracking is especially important for the observation of proper maintenance, completeness, and consistency of data, since multiple departments and functions depend on the database in iPPE. Tracking of statuses ensures that data is properly maintained and completed on time. Object data that can be tracked includes statuses, values, due dates, and responsible persons and organizations. It is also possible to trigger workflows with the status monitor.

To create new correctly maintained objects quickly, users can copy data from existing objects, with the option to include the original object attributes (for example, class, relationships, and details) and structure or to leave them out. The ability to copy entire structures makes it possible to build up similar structures easily. Since the release of DIMP 4.71, users can also compare structures with one other, and look at attributes such as materials, component variants, documents, and so on, within the structure.

PVS

This section focuses on the PVS, or product variant structure, an important iPPE application object that is essentially a super BOM. (Note that some descriptions will use the term CMP, meaning the nodes used to make up the super BOM. Both terms – PVS and CMP – can be used interchangeably).

The PVS is designed for use with configurable, highly variant products. The purpose of the PVS is to provide a redundancy-free description of products or product families with many variants. It offers an integrated data model and enables efficient IT management of the product structure. It also provides a flexible but consistent foundation of data for different views of the product and all areas of the enterprise that work with the product structure. PVS can be used not only for engineering tasks, but also for PLM applications such as product data management (PDM) and SCM applications such as rapid requirements planning in SAP APO (discussed later in this paper). In terms of engineering activities, it should be noted that a connection to a digital mock-up (DMU) viewer and a computer-aided design (CAD) program has been created for PVS. This enables the display and editing of materials and assemblies in three dimensions. Specifications, CAD models, and engineering-support documents can be linked to the PVS. These newly designed interfaces – as well as the document management system (DMS) – are used to optimize the flow of information and provide the user with more information about the engineering production process and the status and progress of production.

The PVS and iPPE routing discussed later in this paper can be maintained as functional structures when the development of a product is beginning. It is not necessary to assign precise materials or activities, for example, at this stage. You can add them to the model at a later phase in product development.

The structure consists of two elements: nodes and variants. Nodes give access to different levels and objects of the product structure, whereas variants represent different characteristics of an object. Nodes can be used more than once and can be arranged in a multilevel hierarchy; normally they have a direct product reference. However, with a PVS no reference to a material number is required, distinguishing it from a standard ERP BOM. While functional structures without a material number reference are often modeled in PLM, direct material relationships should exist prior to production at the latest. In terms of logistical issues, a PVS is the basis for efficient MRP using the RPM.

A PVS and the assemblies within it can be used to maintain BOM data for configurable and nonconfigurable materials, although it is especially well suited for highly configurable materials.

Use of Nodes

A PVS is made up of three basic node elements – access nodes, view nodes, and structure nodes – as shown in Figure 12. Access nodes define the buildable product – a configurable car, for example – and stand on top of the PVS hierarchy, enabling access to the product structure. Access node variants represent the different configuration possibilities for the whole vehicle. Also on this level are the alternatives, as described in the section "Multilevel iPPE Using Alternatives and Accesses."

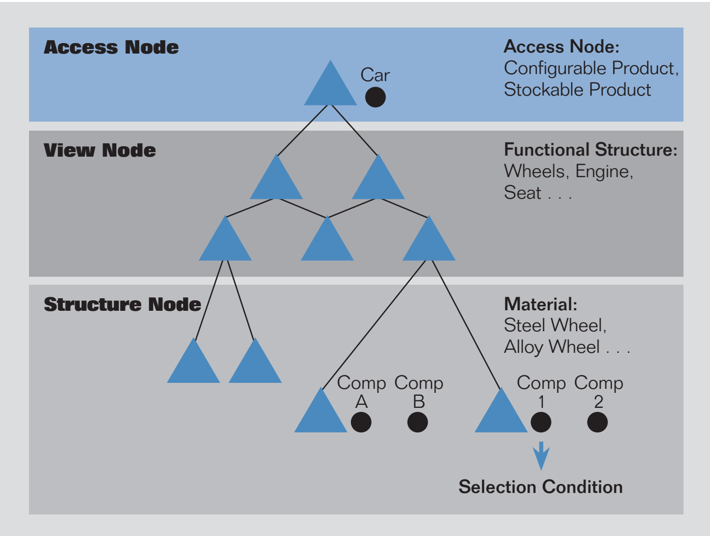

Figure 12: Product Structure for Highly Variant Products

View nodes are functional or logical groupings without any material assignments. Using view nodes, it is possible to set up a multilevel chart that shows the hierarchical relationships to other views or structure nodes. Since view nodes don't contain any material assignments, they are completely ignored during the BOM explosion.

Structure nodes define the components that are used to build up the product. They represent functional groups and product groups, with a defined function and a direct reference to the product, but without any material numbers. Component variants can be defined in the structure nodes to represent the optional parts of the configurable product, such as different types of available engines for a vehicle. These variants are "real" items in the BOM and are strictly related to a component (with an "is type of" relationship). The usage of object dependencies such as selection conditions enables restriction of the components that are actually assigned to a specific variant. In the prototype phase, the variants do not need to have a material reference. But when production starts, the material reference should exist so that material planning and backflushing can be performed. Component variants are also involved in ECM, which is explained in the section titled "ECM."

A structure node can contain multiple component variants; selection conditions used as object dependencies determine the selection options as follows:

- *Multiple selection* allows the selection of more than one component
- A *required component* must be selected
- *Priority* picks the variant with most matches

Structure nodes can be linked to access nodes directly or linked to them indirectly by means of view nodes. It is also possible to build up multilevel structures in iPPE. Normally, the BOM explosion occurs only on a single level; the structure is exploded downward until a material is found, and the intermediate structure levels (view nodes and structure nodes without materials) are ignored. However, multilevel explosion of the structure is also possible if specific data on those levels has been maintained to enable the lower-level explosion. This is necessary when building a product subassembly on a separate production line. The process of multilevel explosion will be discussed in more detail later in this paper.

Selection Conditions

Selection conditions force the selection of PVS component variants, operations in routings, and characteristics in explosion functions. Dependencies are used to select the components that are required for a specific variant. When the structure is exploded, one or more component variants are selected based on the rules assigned to each component variant. These selection conditions are called object dependencies. In a PVS, the only object dependencies that can be maintained are local selection conditions.

You can enter selection conditions using the extended dependency editor in SAP software. First, characteristics must be defined with information derived from the class of the assigned structure node that is relevant for the respective structure node. You can select multiple characteristics. In the second step, the dependencies are defined; the variants determined by the sales order are used by the system for further processing.

Further restrictions can be added, including those with OR or NOT logic. Values can also be entered in a spreadsheet, which becomes especially useful when handling large volumes of data. The characteristics used in selection conditions must be of a single fixed value with no further values allowed and be in CHAR format. As operators, only OR, AND, =, and NOT can be used. If no object dependency logic is entered for a structure node variant, that component will always be selected.

Several checks exist in the software to ensure that the variance scheme is maintained properly. A consistency check is used to test whether the selection of component variants on the structure node unambiguously results in the selection of one or more component variants. It uses the following information when analyzing the node consistency:

- The control indicator *Required Component* on the *Basic Data* screen of the component node, which indicates that at least one variant must be selected
- The control indicator *Multiple Selection* on the *Basic Data* screen of the component node, which shows that more than one variant can be selected
- The control indicator *Standard Variant* on the *Component Variant Detail* screen
- The object dependencies for each PVS variant
- Priority, which determines the variant with the most matches. The software evaluates the dependency of the variant string used; the tie-breaker priority score is the maximum number of characteristics among all terms with the operator OR.

The software checks all factors and displays the consistency of the variants in relation to each other. It also displays color-coded messages about its findings. Yellow messages are for information only, whereas red messages indicate that the variants on the node are inconsistent based on the parameters defined and (or) the object dependencies maintained for each variant.

Meanwhile, a completeness check ensures that a component exists at least once or “n” times based on the object dependencies for a PVS so that nothing is missing. For example, it ensures that vehicles are always equipped with brake shoes. If no component variant is selected for a certain configuration, the variance scheme is incomplete.

An ambiguity check determines whether the object dependencies are ambiguous and result in the multiple selection of component variants. For example, the selection of the vehicle battery is determined by numerous parameters including type of engine, radio, air conditioning, and so on. If object dependencies are not maintained correctly, several different batteries could correspond to the sales-order options. In this case, the ambiguous variance scheme would have overlapping elements.

Collaboration and Project Management

You can use SAP tools for collaboration with other departments in the same company and with external partners.

The document management system allows links between PVS objects and other electronic business objects, such as projects or materials. All linked documents can be included in the various document management processes, such as the use of vaults, versioning, status management, and change management. Viewing and the redlining of objects is possible across the whole company. Occasional users can utilize a simple Web front end that doesn’t require an SAP GUI. In addition, a comprehensive search engine lets users retrieve full text and perform index searches in documents.

The creation of a product can be effectively supported and optimized by using the digital mock-up unit. This modern software tool not only enables the reduction of the costly and time-consuming phase of physically building prototypes, but also provides interactive visualization of the results of product development. You can use the DMU effectively for a wide spectrum of simulation tasks including mechanical collision checks, electromagnetic analyses, heat development, and assessment of the feasibility of assembly. This simulation option is especially helpful in engineering the design of products that have many variants, because it enables users to take into account all aspects of the product. They can view a product structure model across the whole logistics process chain through the integrated CAD viewer.

The DMU enables the design of simulations and analyses using the integrated virtual PDM (VPDM) solution, and allows users to update the structure model afterward.

With the Internet transaction server (ITS) in SAP software, you can “check out” or “check in” objects to a development partner for viewing and editing after replication in the partner work area via Extensible Markup Language (XML).

Handling of Colors
Nodes with assigned color variants possess a specific color characteristic included in their material number, but these numbers only represent the possible colors of a part, not the part itself. However, they do show object dependencies as well as a history within change management. To use colors, it is advisable to first create a neutral color node that contains all possible color codes as variants, but has no material assignments. The color node variants are used to define colored materials afterward. You must previously define offset and length of the color codes in customizing software using the transaction *OPPE01*. In a second step, two types of material numbers must be maintained for each component that can have different colors: a color-independent material, and a color-specific material that has the color code appended in its material number. The color-independent material then has to be assigned to the corresponding component variant (thus, the existing materials are replaced with the color-independent materials maintained previously), followed by the assignment of the color node to the very same component variant. Note that the object dependencies for the color code must be maintained on the color node, not on the component variant. Giving color schemes their own nodes enables the use of these nodes in several structures, if they share the same schemes.

Assembly Options
Configurable components possess variants whose selection is based on object dependencies. However, you can also use subordinate nonconfigurable assembly components that are automatically selected if the higher-level parent component is selected. These parent nodes are called “assembly nodes” and represent single-level BOM structures. Multilevel structures can also be built using assembly nodes; however, you can only use one level at a time. Since the subordinate parts are fixed, no object dependencies are available for assembly nodes; with the use of the parent object, all child objects are selected automatically. However, it is possible to assign child components to several parent components that share the same parts to a great extent (for example, two types of brake systems).

Another option is the use of “phantom assembly nodes” in iPPE. Phantoms are parent assemblies that are never planned or received into stock. Rather, the BOM explosion skips this level and directly explodes the child components. To build phantom assembly structures, several preconditions have to be fulfilled. A vehicle with an access node must exist, and there must be a structure node with component variants, object dependencies, and materials. There must also be an assembly node with child components and the same materials master in the header as the structure node. This assembly node is then defined as a phantom assembly in the component variant details screen of the structure node.

In phantom assembly, assembly components are directly linked to the structure node variant, whereas in standard assembly, the assembly header is linked to the structure node variant and assembly components are only visible at the lower level. The iPPE structure affects the planning results during the BOM explosion. For phantom assemblies, assembly components are planned directly. For standard assemblies, the assembly header is planned first and assembly components are planned in the next step.

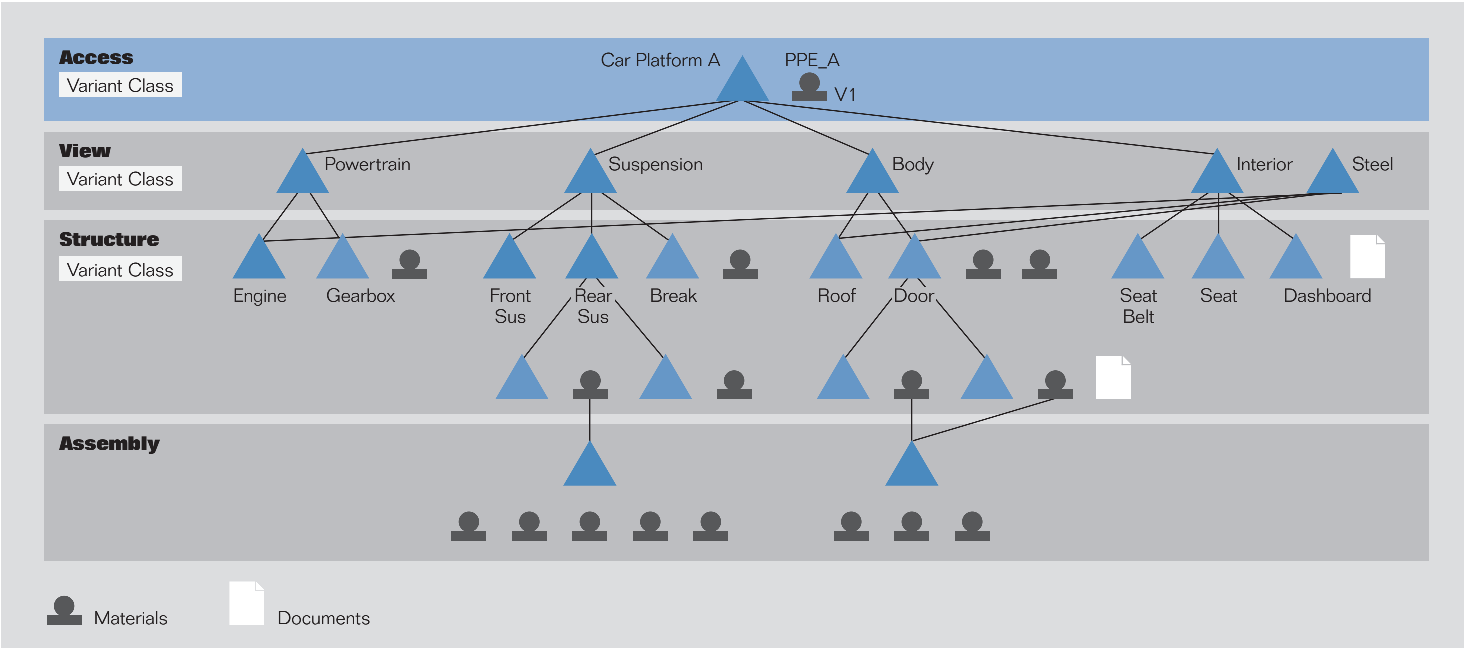

Figure 13: Multilevel iPPE

Multilevel iPPE Using Alternatives and Accesses
This section deals with the possibilities of linking several types of nodes together in a hierarchical structure. Note that object dependencies and document assignments exist only on the structure node level, and that view nodes don't have any assignments at all. All node types except the assembly nodes must be assigned to a variant class. Figure 13 provides an overview of a multilevel structure.

Except for view nodes, all nodes in the top-down object structure are linked through alternatives. You can use multiple alternatives, allowing the parent node to link to different child nodes depending on the context[1] – for example, production versus engineering. Alternatives can be used to build products in multiple ways using different explosion paths. Alternatives that provide different views of the same structure are also important for the sharing of common data across different applications, such as production and engineering. Alternatives allow iPPE structures to be modeled to meet specific users' needs, and at the same time, vary flexibly for a wide range of potential users. For example, you can create engineering and production views for the same structure but with different submember structure nodes. It is also possible to relate one structure node to multiple applications.

To build a complete hierarchical structure, however, alternatives alone are not enough – it is also necessary to create "accesses." An access is a one-to-one combination of a variant and an alternative in which the variant represents the manufactured material and the alternative represents how to build the material. Creating an access links these two pieces of information. It also provides period validity, plant validity, and usage validity. Creating an access is essential to enable production processes such as PVS explosion.

1. It is possible to change the usage of alternatives in SAP software.

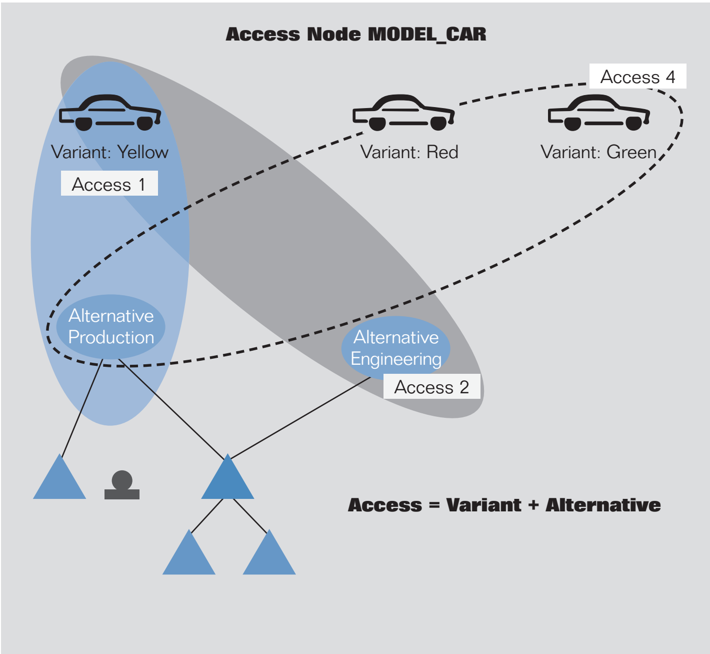

Figure 14: Defining an Access

Figure 14 provides a graphical representation of the access concept. The access node contains three variants (shown here as end-item cars) and has two alternatives for production and engineering. Multiple accesses can be created through different combinations of variants and alternatives. This concept applies not only to access nodes, but also to structure nodes. And component variants can be combined with alternatives to create an access.

Accesses are also available at assembly node levels, but the process is slightly different. In this case, the variant (assembly node header) is combined with the alternative to form an access. Note that the access is made at the assembly node and not at the structure node. While the material assigned both to the structure node component variant and to the assembly header is the same, you must define the actual access at the assembly node. Multiple alternatives and accesses at the assembly node are also possible. However, you can only use one alternative for documentation. A standard alternative for any assembly node is automatically created by the standard customizing software.

Variants, alternatives, and accesses demonstrate the flexibility of the iPPE PVS compared to a standard BOM. The standard BOM in SAP ERP can handle only one technical type at a time: simple, variant, or multiple. The simple type is set for BOMs with one material that is built the same way (with the same components) every time. The variant type is set for BOMs that include several products; the components used depend on variant configuration and there is only one way to build the products. The multiple type is set for BOMs with one material; the components used depend on the lot size or other selection options, and there are several ways to build the product (usually with only slight differences). Using variants, alternatives, and accesses in iPPE, it is possible to model all types in the same structure.

"Side access" is functionality available for the display of multilevel configurations (header and component configurable materials) in one simulation explosion. This multiple configuration is called "nested families" because the second configuration is nested within the first configuration. A typical example is the configuration of a car at the top level, with a configurable engine. Based on the engine selected for the car, fixed rules can determine which components will be used in the engine. These selections can run automatically in the background, but can also be viewed if necessary.

The advantage of using nested families is that you don't need to view the configuration of the component unless it is specifically necessary. Another advantage is that component configuration is nearly independent of header vehicle configuration. This is necessary for building configured components separately from the vehicle. Nested families allow the representation of lower-level structures without having to specify characteristic values at higher levels. This is done by maintaining separate configuration profiles and separate access nodes for these structures. You can only use nested families if an alternative is maintained at the second access node. Also, the nested family explosion is possible only in simulation mode – the actual planning explosion is done on a level-by-level basis. In the simulation, the characteristic value for the component is transferred to the component access node. Side access is required to perform rapid planning for level n components.

Focus Objects

A focus object is built to make specific modifications to the general PVS product model without changing the original PVS model – these modifications can only be seen in the focus context. Within a focus, you can add or exclude specific objects from the general product model; you can build individual structures on the basis of the general product model. Like a PVS, a focus has several objects and the same types of nodes: access nodes, structure nodes, and view nodes.

There are three possible types of iPPE objects within a focus:

- Reference objects that appear in the focus and the master structure but can only be changed outside of the focus filter
- Copied iPPE objects within a focus that have no reference to the original source structure; these can be modified independently within the focus
- Objects specifically created in a focus, which are then visible only within this focus and have no individual view outside of this focus

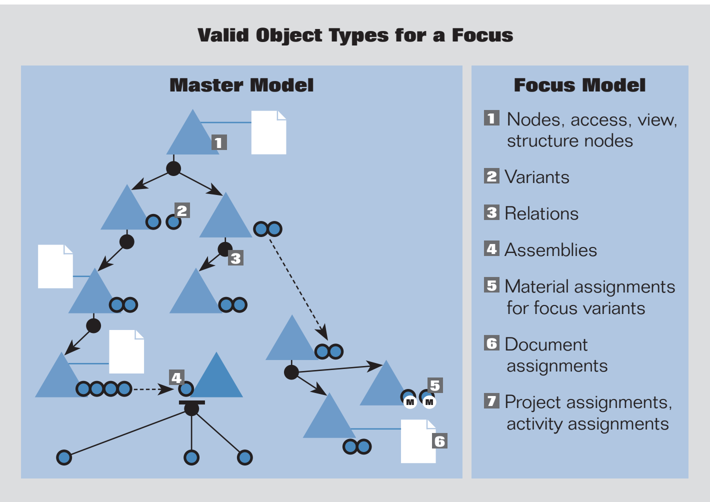

Figure 15: Overview of Focus Objects

Figure 15 provides an overview of the objects types that are valid within a focus.

There are different types of focus structures in iPPE. A **fully configured focus** contains a copy of the material, with all data, in a focus context. Once the focus is saved, changes to this focus are no longer accepted. A **focus with variants** represents a copy of a partially configured material, and changes can be made to the material, plant, and usage even after this focus is saved. A **partner focus** contains individual structures that can be developed further by a partner or external supplier. There are two new options in DIMP 4.7: extraction for editing (in which the focus can still be changed), and extracted and completed (in which the focus can no longer be changed).

The assignment of iPPE objects to a focus is always done by assigning a material with an already-defined access. Several possibilities exist for the assignment: A focus can be linked to a PVS at any structure level except the access level. A focus can also be defined with an access of its own.

Note that focus structure nodes are the lowest level for focus objects in terms of granularity. No focus-specific variants are possible. Also, PVS and focus objects can be copied into a focus, but you can't copy focus structures into a PVS. All focus elements can be maintained in the iPPE workbench using several display filters, such as objects in active focus, unlinked object, and so on. Although filters, focus structures, and view nodes might appear to be similar, different concepts underlie each object. For example, a filter is used only to modify the display of objects seen on the screen. You can't make functional or structural changes with a filter, although a filter can be saved.

Meanwhile, focus structures are used to group together specific structures of a master PVS for development changes, deletions, or structure additions. A focus is only intended to provide a product development environment that is distinct from the master product model. It is designed to have one fixed configuration; if other configurations are needed, a new focus should be created. Also, the use of different filters within a focus is not intended. Focus-dependent parameters such as effectiveness and characteristic values should be stored directly in the focus header. Although focus structures and filters are activated from the same subscreen in iPPE, you can't have both a focus and a filter active at the same time.

A view node is an iPPE object – as is a focus – that is used to group together other view or structure nodes. You can use view nodes to group together logical substructures or in phantom assemblies.

The Process Model: ACT

With SAP software, the process structure, or ACT, is used to maintain routing data. There is an interface for connecting time-analysis products to the iPPE routing (process structure), and processing times can be determined and transferred to iPPE. Engineering and manufacturing are both supported by the separate but integrated modeling on a logical level (as a node without material and resource assignments) and on a specific level (as specific process variants). The ACT enables networked multilevel process modeling with a sales operations plan, installment plan, routing, and operations. It provides a priority graph data model for modeling routings and material flows (resource networks) instead of just using simple routing sequences. It also makes it possible to apply nodes in multiple ways. Assignment of the process model and ACT product classes and resources and assignment to the RPM and line design will be discussed later in this paper.

The ACT contains several node types used to maintain the process model (see Figure 16).

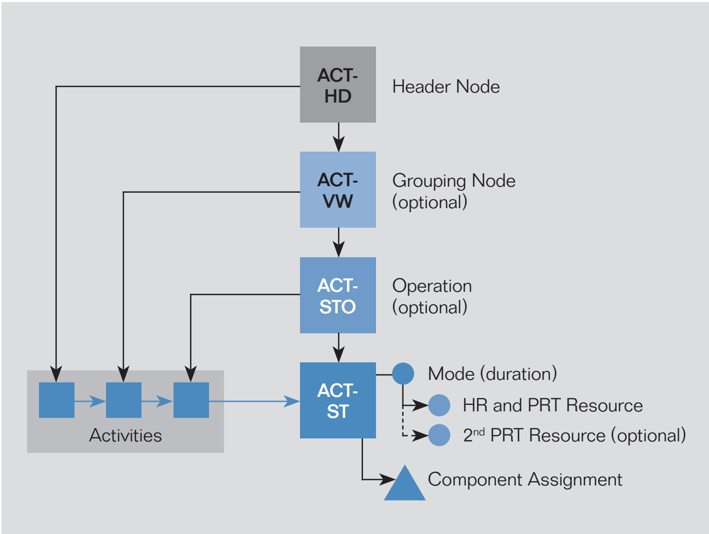

Figure 16: Activity Node Types

The header node represents the highest level of the process model and stores the header data and activity sequence. It is always required.

The grouping node is used to group several activities and operations together. It can be used to build up multilevel process hierarchies together with lower level grouping nodes. Grouping nodes are optional.

Operation nodes group activities together for joint execution. They are similar to grouping nodes but there are several differences in how they respond to the selection of configurable components. Operations can't be used to create multilevel hierarchies. Similar to grouping nodes, operation objects are optional.

Activities are the basic elements of a process model. They describe how a process step is executed. Only activities contain the actual work content. The mode of activities describes how and where these activities are executed. Using activities you can define certain operation sequences.

iPPE Activities and Assignments

An activity node is a single work step; it contains data such as job description and capacity requirements. Activity nodes can be used in multiple operations or grouping nodes. An activity node receives the assignment of PVS components or variants as input. The input relationship determines if an activity is required or optional. If the component-required flag is set in the assigned PVS structure node, the activity will always be performed. An activity is always executed if no input relationships exist. Input relationships may only be assigned to activities. The deactivation of activities without links can be done only by using operations.

An activity node at the lowest level of the process structure can be linked to a header, an operation, and (or) a grouping node. All activities are arranged in a sequence that determines the execution order. The mode of activity nodes is used to assign activities to resources. Alternative modes are possible so that an activity can be assigned to several resources (for example, in different plants).

There is a difference in how activities assigned to grouping and operation nodes respond to component variant assignment. Grouping nodes structure several activities for multiple uses, and activities in a grouping node are not performed if there is component linkage and the component is not selected. Operation nodes group activities together for joint execution, and an activity in an operation node is not performed if it has a component allocation or a related activity (via the operation) and the component is not selected. In other words, the activities related to a grouping node behave independently, while activities related to an operation are either all activated or all deactivated.

Use of Resource Nodes

While activities are used to describe process steps, the actual work content is maintained in resources. A resource can be a machine, person, facility, warehouse, means of transportation, or other asset with a limited capacity that fulfills a particular function in the supply chain and is used to perform operations. Resources are related to factory layout through a line balance. This topic is covered in the section "Line Balance and Model Mix." Figure 17 gives an overview.

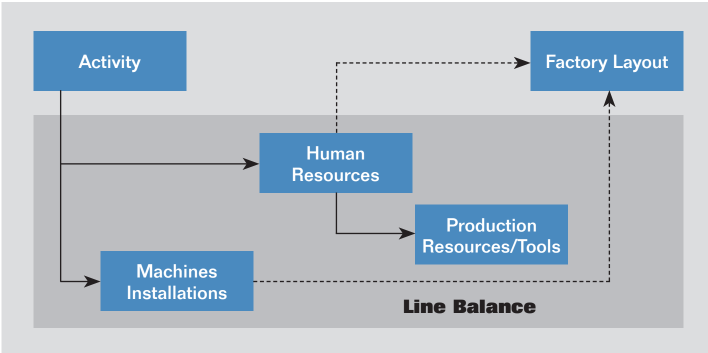

Figure 17: Resource Nodes

HR resources are mapped with the resource mode type "workers." A connection to labor resource planning is created at a later point in time. Workers and operating facilities have similar functions but different attributes.

There are several mode resources for operation facilities. For example, you can map PRTs – production resources and tools. These are movable operating resources that are used in production or plant maintenance to fulfill certain tasks.

Two types of operating resources are used in SAP ERP: materials and documents.

Since the release of DIMP 4.71 , planning resources are also available as a third resource type. Planning resources are plant-specific, and only the resource type is sent to SAP APO (if the capacity planning flag is set). There are several planning resource types available: single, multi, bucket, single-mix, and multimix.[2]

Mode resources are used for several activities, such as activity cost calculation, assignment to factory line objects (via line balancing), or activity backflush (with the RPM).

2. Since the release DIMP 4.71/iPPE 2.0, class assignment of resources is no longer allowable and must be deleted (see SAP note 652829 for further information).

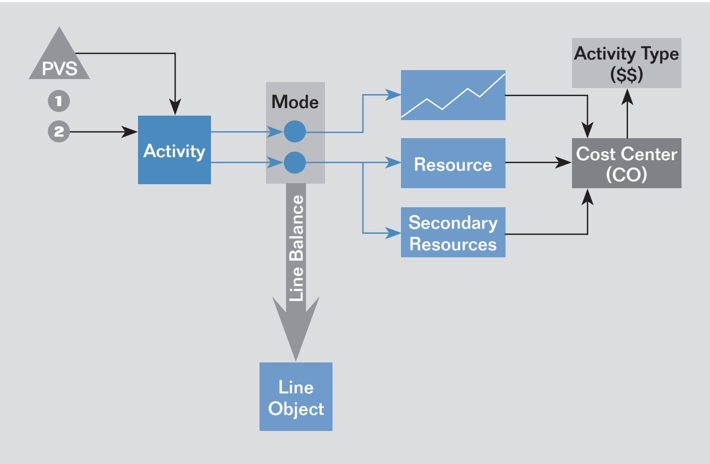

Figure 18: Process Structure Data Model

However, capacity constraints of mode resources cannot be considered in SAP ERP or SAP APO. The capacity of mode resources is not the basis for vehicle scheduling; rather the load at mode resources can act as an input to determine the takt time, in addition to other inputs. Takt time is the basis for vehicle scheduling.

Figure 18 provides an overview of the assignments structure. There are several ways to connect the PVS to an activity. Connecting the whole structure node, for example, assigns all component variants that are assigned to the activity. You can also assign one or multiple individual component variants to an activity. The selection condition for the activity (object dependency) is inherited from the PVS object.

You can assign activity modes to line objects via a valid line balance. An activity can contain multiple (alternative) links; therefore, multiple links to multiple line objects are possible. Line object modes are also assigned to resources that contain operation durations and costing information for activity costing at the backflush. Resources are plant-specific and determined via mode details. Only planning resources are sent to SAP APO if the capacity planning flag is set. The final settlement of resources takes place in the appropriate cost center with cost calculation of the activities depending on the activity type.

Factory Layout and Line Design

While CMP nodes are used to model the super BOM, and ACT objects are used to model super routing, factory layout objects (FLOs) are used to model the factory or production plant. FLOs include lines, work stations, and alternative lines, and have links to production line resources. A so-called "super factory layout" is not possible since a production facility does not dynamically change based on sales-order criteria.

Line design enables flexible structuring of the production environment with single or multiple structures. Line objects are grouped into a hierarchy called a line network. This line network is used to plan production of the finished item through the plant, considering factors such as takt times and paths.

Structuring of a Line

The line net groups line objects together in a hierarchical network. It is the header node and is mandatory because it contains line balance information. It is also required in the production version. The production line below the header is an object that can be planned independently and is linked to a (mandatory) resource for the definition of available work times. Resources at this level are unique and can't be shared with other objects; they also represent the basis for scheduling. A line object can also contain a supply area for PVS components, as well as an action point (formerly called a reporting point) that is used primarily for backflushing and production tracking. Scheduling takes place only on the line level and forms the basis for precise component demand planning in the RPM (concerning demand date and time), thus enabling easy capacity planning in repetitive manufacturing, as planning is based only on production rates. Furthermore, resources enable backflush and line-balancing activities. At least one line should exist in the line structure. Optional line segments allow the division of the line into smaller structures[3] using further hierarchies. Line segments also can have supply areas and action points assigned. Work packages (jobs) divide the segments further, allowing, for example, the defining of the left and right sides of a station.

3. It is not possible to plan at the segment level as there are no resources there.

Because this node type can only contain a supply area, it does not allow for scheduling and reporting; work areas are used to differentiate inventory supply locations. Buffers allow areas where finished items can wait for a certain period of time. All line objects are plant-specific. While CMP and ACT objects can be used at multiple plants, FLOs are fixed for a given location.

Figure 19 gives an overview of the different line structures.

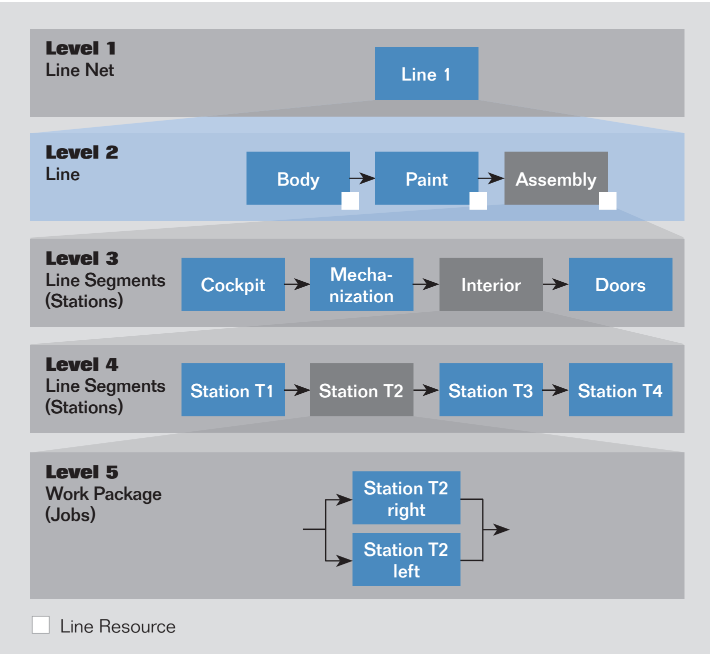

Figure 19: Structure of a Line

Takt Scheduling

The planned takt time is the interval between the time a product enters the production line and the time a processed product leaves the line. Takt time scheduling equals the fixed takt time multiplied by the number of takts. Using this technique, simple scheduling of high volumes in a short period of time is possible. Since the rate is dependent upon the line resource, the number of takts does not influence the output. What does change is the number of pieces with WIP status and the total time each piece is worked on; this does have an impact on stock levels. The takt rate (pieces per hour) is defined in the line resource, so the focus of takt scheduling is on activities (ACT) and routings. In contrast, lead-time scheduling cumulates labor and machine requirements to determine the total working time. Unproductive time intervals, such as waiting or transport times, are not considered in lead-time scheduling; therefore errors can be encountered. In takt scheduling, unproductive time intervals are defined as well (see Figure 20).

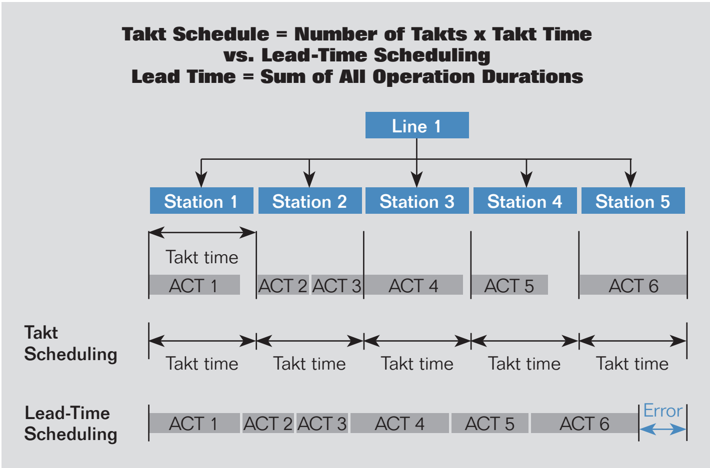

Figure 20: Takt Scheduling and Lead-Time Scheduling

Setting Up Relationships Between iPPE Application Objects

One of the key benefits provided by iPPE is the ability to relate all the applications involved in the process. This section focuses on the integration of previously built master data. The PVS is related to the ACT by the linkage of materials to activities; material assignment is carried out via structure nodes or their variants. The activity structure is related to the factory layout by linkage of activities to plant locations via the activity modes.

Supply Areas

Since all line objects are attached to a specific plant, the corresponding supply area must also be found in that same plant. The supply area can be attached to a storage location (for inventory management) or to a bin (for warehouse management). It represents the basis for using supply to line (S2L) and (or) functionalities of the lean manufacturing method, kanban. It is possible to maintain and view control cycles directly in the FLO structure.

Different work centers can be assigned to a line through the use of work packages. This provides you with the option to define specifically where a component is to be used, which is essential for S2L or kanban operations. For example, work packages or supply areas can be assigned to only one side of a line station.

Demand Times Calculation and Action Points

With this degree of integration of master data, it is possible to determine exactly when and where a component is required. Action points have reporting-point functionality for production confirmations. In addition, action points can be integrated with the production action handler (discussed later in this paper) to interface with a shop-floor system. The attributes of action points are maintainable; therefore, an action point can act as a reporting point, a tracking point (action handler), or both (see Figures 21 and 22 for more details).

Although action points can be created in SAP ERP, you can only maintain the complete attributes for tracking and printing in SAP APO because the action handler functionality is part of SAP APO. Action points are discussed later in this document.

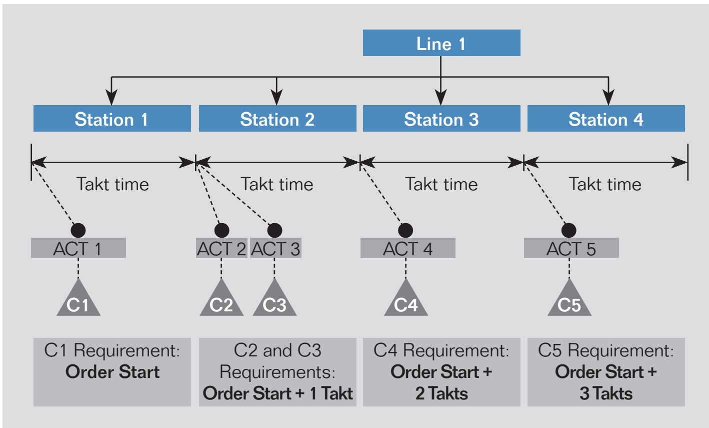

Figure 21: Calculation of Component Demand Times

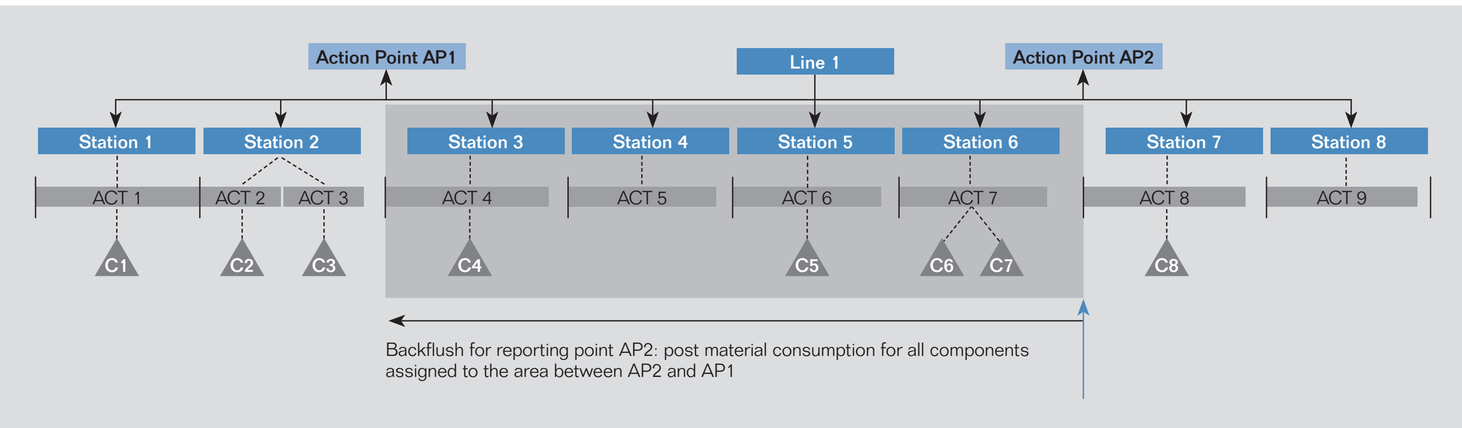

Figure 22: Action Point in a Line

Line Balance and Model Mix
Line balance functionality is used to link ACT (the process structure) and factory layout. Mode resources are related to line objects through the context of a line balance. By assigning operations to a station or jobs you can achieve an optimal work load of the station or jobs. Line balance has specific date validity – that is, while it is possible to create multiple line balances, only one can be valid at any specific point in time. By creating multiple line balances, you can specify the point in time and character of a change in line structure or resource allocation. Due to the linkages in line balance, the exact point in time that a component is needed can be easily calculated using the takt scheduling logic. Information from process engineering can also be used in manufacturing due to shared databases. Several versions of line balancing can be defined to compare different alternatives. The graphical representation of line balances in iPPE enables you to simulate different ratios between several products and allows you to use Drag&Relate to move operations between line segments.

To determine if a line is properly balanced, a model mix has to be created and assigned to the line balance. A model mix represents the relative percentage of different vehicle models and can be assigned to the line balance as a basis for line balancing. A model mix contains a list of vehicles (and their proportions) built on a particular line. Depending on the configuration, vehicles in the model mix may or may not require certain components. Based on the component selection, certain activities may or may not be required to build the vehicle.

If activity line assignment happened without any model-mix calculation, a car with all possible components would be built. Using model-mix calculation lets the system calculate weighted durations from average labor requirements for the specific model mix. To determine the weighted duration, the labor content is multiplied by the percentage of usage.[4] If the specified model mix is not possible within the allocated tact time, the user can address the issue with various strategies: the model mix can be changed; an operation can be allocated to another station; the takt time or the capacity (number of resources) can be increased; or the activity times can be decreased by, for example, the allocation of more resources or a change in the process. If the average weighted takt is equal to or smaller than the takt time, the line is balanced. Thus, the process of using multiple specific model mixes to determine whether the activity assignment matches the given takt time is called line balancing.[5]

Model mix planning (MMP) is performed in SAP APO. The MMP process uses an algorithm to determine an optimal vehicle production plan by scheduling planned orders to the line network. In this way, it ensures adherence to capacity constraints and other user-specific restrictions. Several planning algorithms exist for the calculation of an optimal vehicle production plan; line balance is a key input in this planning process. MMP is discussed later in this document.

ECM
Software for engineering change management, or ECM, is a central, integral part of PDM functionality in SAP ERP and ensures a complete history of any changes made to product data. The components used for ECM enable companies to do the following:
- Master data management (material master records, PVS, activity modes)
- Document management
- Classification
- System access through a CAD interface
- Workflow
- Variant configuration

ECM software can be used to edit PVS variants and modes; SAP ERP is thereby able to make operational use of different status changes. Without this software, there is exactly one valid status for each object in the system.

4. If a component (and therefore, an activity) is not required for a certain car, the weighted average will be less than 100% of the actual production time.

5. While there are some analytic functions in iPPE, SAP offers interfaces to partner products for more detailed analysis.

ECM software enables the monitoring and seamless documentation of changes according to the notification settings, as well as planning and conversion for defined effectivities. Multiple change statuses can be stored for single ERP objects (for example, BOMs and routings). This means that the objects can be stored historically for all relevant change statuses. For a smooth process flow, ECM software is integrated in the logistic process chain. The changes automatically take effect in areas of the logistics process chain (for example, the sales order, material requirements planning, shop floor, and production control areas) when a corresponding release key is set. Changes that belong together can be grouped for different objects simultaneously or for different points in time, with the possibility of using cross-applications and special documentation. This is useful if several ERP objects are affected by one change. When a user defines a validity in a change master record (or change order), the changes only become effective at this defined validity. Depending on the dates that define the validity, the validity interval can have, for example, a temporal reference (date interval) or a reference to any parameters (for example, serial number interval).

Handling of Documents and Objects

Object changes (for example, in BOMs or routings) can be performed with or without historical information in SAP ERP. The application generates change documents for changes without history, but the change statuses are not saved. This approach is used with changes that do not need to be documented, such as those that take place during the product development stage. The status of the object before the change is not saved either. The object's status can only be obtained indirectly before the change takes place by using change documents.

Changes with history need to be documented, such as those that take place during production. Both the status before and after the change is saved, and the application generates change documents. For some objects, these change documents differ from those generated for changes without history. Change management software in SAP ERP enables the complete documentation of changes, which may be needed for issues such as protection against product liability.

It is possible for ECM software to support the business process of requesting, checking, and releasing a change by using an engineering change request (ECR). An ECR can be converted to an engineering change order (ECO) later in the process. In this case, the ECR or ECO takes the place of the change master record. An ECR or ECO has similar functions and structure to a change master record; however, it also supports the comprehensive status management process that is the basis for the complex change. The valid-from date and the affected objects normally are not known when the process begins.

Status management functionality for an ECR or ECO also forms the basis for the integration of the SAP Business Workflow tool in ECM software. It enables users to organize the cooperation of several departments regarding planned changes. When an ECR or ECO is created a change type must be defined. A change type can be used to link to different business processes for requesting, checking, and releasing a change. The change type of an ECR or ECO is the requirement for connection to SAP Business Workflow or to a digital signature.

A change master record consists of several parts. The change header contains a short description of the change reason, the valid-from date, and the change status. Certain objects, such as material master objects, component variants, and activity modes, can be selected so that they can be changed in their material master records. Users can document changes to a specific object, such as a material, in object management records. Alternative dates enable more precise control of the valid-from date of individual objects. Accompanying documents can be allocated to the change master record. Classification can be used to search for specific change master records.

Object-type indicators are used to control change-number processing for different object types, such as object management master records. There are three iPPE-related object types: PVS variant, PVS mode, and PVS dependency. Table 6 provides an overview of the different indicators.

INDICATOR	DESCRIPTION
Active	Signifies an object type for change numbers. Objects of this type can be processed with a change number.
Object	Indicates that each object of this type requires an object management record. You can only make changes to this type of object if an object management record has already been created for it.
MgtRec	Means that an object management record is generated. An object management record is automatically generated if an object of this type is created or changed with a change number. In this case, all objects of this type with the change number can be modified.
Gen New	Means generate only on first creation. An object management record is automatically generated only when an object of this object type is first created.
GenDial	Means generate in dialog. When the software automatically generates an object it opens a dialog box in which object-specific documentation can be entered.
Lock	Means that the object type is locked against changes. Lock can be set and released if necessary.

Table 6: Object Type Indicators

Object management records form an independent master record in SAP ERP that can only be created in connection with a change master record, ECR, or ECO. When you enter objects in the object overview of the change master record, an object management record is created in the background. Any number of object management records can be created for a change master record for materials, BOMs, task lists, and documents. One object management record controls exactly one change object in order to realize a change in status management. It provides functionality for specific documentation and the object-related status network (user status). The assigned object is uniquely identified by its ID, (for example, a material master is identified by its material number). A change made to the assigned object with reference to the change number becomes effective from the valid-from date. This date is taken from the change header. You can, however, override it by using an alternative date. Assigned objects can be locked against changes by using the lock function for the change number. Administrative data for the object management record specifies the date of creation or change, as well as the person who created or changed the record.

Hierarchies in change master records enable the clear structuring and control of complex product changes. Furthermore, changes can be handed over to the functional areas as single logical units. An important attribute of the change hierarchy is that it enables users to define changes with organizational impact on the level of change packages, and to attach workflow and status objects to the change packages. Some parameters of change packages can be maintained centrally (that is, globally).

The alternative date assignment function allows you to specify multiple effectivity start dates in the same change order. An alternative date can only be assigned to a specific object, so object management records must be activated. Inside the change order, an alternative date is defined (text description + date) and then assigned to the specific object. When the change order is applied to master data, all master data affected by the ECR will adopt the change master from the change header, and those objects attached to the alternative date will become valid from the alternative date onward.

Using ECM software, it is possible to monitor the history of additions and deletions of variant positions in iPPE.

Effectivity Parameters

Generally, the effectivity of changes maintained with change numbers is determined by the valid-from date. In SAP ERP, the effectivity of change numbers can be fixed to other effectivity parameters. You can assign effectivity parameters when maintaining change numbers and when using objects that have been edited with such change numbers. The effectivity parameters time interval (DATE), serial-number interval (SERNR), and material number (MATNR) are defined as standard in the software. It is also possible to define additional company-specific effectivity types. Because it is practically impossible to establish all imaginable variants of effectivity types within the scope of standard software, customizing for ECM allows the determination of other effectivity types with freely definable parameters. To apply specific effectivity start dates, the effectivity type must be specified in the change header. Depending on the parameters defined by the effectivity type, the change order will be applied only to those items meeting these specific criteria.

The start-up parameter can be used to apply future engineering changes to current production vehicles. For example, this functionality can be useful for building prototype and preproduction vehicles. In order to use a start-up parameter in ECM, a start-up characteristic and characteristic value must be maintained in classification. An engineering change number (ECN) with the PVS effectivity type and a value for the start-up parameter must be entered. The ECN must then be applied to the variant. The characteristic value must be selected during the explosion (either a simulation or an actual sales order) in order to use the specific changes that are assigned to this ECN with the start-up parameter. By using the start-up parameter, you can incorporate engineering changes earlier than is usual. This can happen, for example, if a customer orders a vehicle in the current year, but actually wants that same model as offered in the following year. It should be noted that including a start-up parameter in the filter dialog will change the selection result.

Production Planning

The first part of this section elaborates on the integration of SAP APO and SAP ERP, describing the associated software interfaces and data transfer. The second part deals with production planning, MMP, and interactive sequencing, and explains the concept of SAP liveCache technology. The third part provides an in-depth examination of the MRP process with RPM, and compares the use of this type of algorithm with the usual MRP approach.

Integration of SAP APO and SAP ERP

Before sending iPPE data from SAP ERP to SAP APO, a production version of the data must be created in SAP ERP. The production version tells the software which BOM (PVS), routing (ACT), and line (FLO) to use when the product is manufactured. In general, production versions can have date- and lot-size validity in the software. In the automotive industry approach, however, only date validity is allowed because the lot size is always one – only one vehicle is built at a time, and it is independent of the volume of the whole batch of vehicles. The production version is strongly related to an access (the combination of a variant and an alternative) in the PVS node. All related master data is copied in the integration model automatically.

Also, a product cost collector must be created for each vehicle the company plans to produce. During production, all costs (material, labor, and overhead) will be collected against this order. At period closing, these costs will be settled to the appropriate financial accounts. The cost collector requires the existence of a production version for the costed material.

In terms of individual and collective requirements, all level 0 requirements (for the vehicle) are covered with sales-order stock – that is, finished goods produced specifically for a particular sales order. With a sales order, you create individual customer requirements, which are transferred to production for material planning.

After production, the goods receipt is posted to sales-order stock. When you create deliveries and posting goods issues (GIs) you reduce sales-order stock. Sales-order-specific billing documents are created in the sales and distribution area.

You can also plan lower-level component requirements for a specific order. The inventory for these materials must be assigned to a specific sales order; backflush is not possible if there is no sales order stock. In this case, the total material inventory is irrelevant.

Lower-level materials can also be planned as collective requirements. These requirements are aggregated for all vehicles, whereby backflush can be carried out for any order.

The software performs better with collective requirements planning because that requires fewer planning entries. If a parent item is planned as a collective requirement, its components must be planned in the same way.

Integration Interfaces

Because SAP APO is a planning engine, it must retrieve master data and transaction data from other software, such as SAP ERP, via an interface. A CIF – or core interface – has already been defined to send data between SAP ERP and SAP APO.

SAP APO can also communicate with non-SAP software such as legacy or third-party applications. For these situations, a BAPI® programming interface is available. However, it must be programmed as part of the implementation project effort.

To enable the planning functions in SAP APO, data from SAP ERP must be sent to SAP APO using the CIF, including sales orders, purchase orders, production orders, inventory levels, and iPPE objects. Once the data is received in SAP APO, additional maintenance (data fields, parameter settings, and so on) may be required. The CIF supports both initial and incremental transfer of data.

The creation of SAP liveCache data and its updating also take place in SAP APO. The concept of SAP liveCache is explained later in this document.

Integration Models and Data Transfer

The interface alone is not sufficient to start data transfer between SAP ERP and SAP APO. In order to send data, an integration model must be created. This occurs in two steps: first, the model identifying the data to be sent must be built; and second, the model must be activated to actually send the data to SAP APO.

You do not need to have all of the available master data and transaction data in SAP APO in order to perform planning in this component. The data objects to be selected from the total dataset in SAP ERP for the transfer to SAP APO are specified in the integration model. To create this model, first select the object types (for example, material masters). Next, specific selection criteria can be used (usually a material-plant combination) to further restrict the object types already selected. For example, an MRP controller can be entered for the selected material masters. In this way, the so-called filter objects are defined. These filter objects are used to select which data objects are transferred to a specified SAP APO software system.

Because the software does not save the selection options you make when creating an integration model, the settings have to be saved as variants on the selection screen. With this approach, saved settings can be reused at any time. If an integration model must be recreated at a later point in time, the required variant can then be called up in the selection screen. Changing an existing variant of the integration model is not recommended: instead, a new version should be generated, followed by the deletion of the previous variant.

If an integration model is regenerated (modified to reflect a change), the software automatically generates a new version of this model. Different versions of an integration model are distinguished by their date and time of creation, as well as by the filter objects that they contain. Any number of versions of an integration model can be created, but only one version can be active at a time.

The structure of an integration model influences system performance. When the software integrates transaction data, it checks whether the data concerned is contained in the active integration model. At the same time, it loads and interprets all active integration models for the object type in question in order to determine any target systems that may be affected. The greater the number of integration models per object type, the longer the runtime to determine target systems.[6] If no further restrictions are made to the object type, the software automatically selects all objects for this object type (for example, all material masters). This can lead to significant performance problems.

Integration models must be activated to trigger the initial transfer of data from SAP ERP to SAP APO. Integration models that are no longer needed can be subsequently deactivated and deleted. As long as an integration model is active, both systems will continue to communicate data.

The customizing and default settings for integration must be maintained in both SAP APO and SAP ERP. The relationship between the source and target software systems must also be maintained in both systems.

Table 7 provides an overview of object types and an activation sequence. Table 8 shows which objects should be grouped together in a separate integration model and what sequence they should be activated in. Integration models must be generated and activated in the right sequence or data transfer will be blocked in SAP APO.

NO.	OBJECT TYPE
1	Available-to-promise (ATP) customizing and product allocation customizing
2	Plant (including distribution centers)
3	Classes and characteristics
4	Material masters
5	Networks
6	Maintenance orders
7	MRP areas
8	Planning product
9	Availability check
10	Product allocation
11	Customer and vendor data (may need to be separated)
12	Work centers
13	Production process model
14	Delivery schedules, contracts, and purchasing information records

Table 7: Object Types and Activation Sequence

NO.	OBJECT TYPE
1	Stocks (customers and vendors with special stock must be included)
2	Sales orders (sales orders, deliveries, scheduling agreements, quotations, and customer independent requirements)
3	Purchase orders and purchase requisitions
4	Production (process) orders and planned orders (activation before production starts)
5	Manual reservations and planned independent requirements
6	Production campaigns and process (planned) orders
7	Shipments

Table 8: Grouping of Objects and Activation Sequence

At least one integration model must be created for all existing production versions with an iPPE access object in order to provide the SAP APO software system with the initial iPPE data. The integration model groups together all the iPPE structures that should be transferred, as well as the dependent data of the selected products.

6. For performance reasons, it is recommended that master and transaction data not be entered into the same integration model. If possible, use only one object type for each integration model.

The software uses the product numbers to determine the production versions with iPPE access objects. Dependent objects (master data such as product masters for components, classes, and resources) are included in the integration model. In order for a transfer to be successful, a production version with an iPPE access object can be included in only one active integration model; other integration models must be deactivated. Transfer starts with activation of the integration model. However, only the first level of a PVS is transferred; multilevel structures must be sent level by level. Additional production versions must be created for component variants of lower levels if they have to be transferred. Line balances are only transferred if they fall within the validity period and are relevant for planning. Users can specify whether line balances at lower levels of the line hierarchy should also be transferred. Line balances are deleted completely from SAP ERP and recreated in SAP APO. Therefore, it is essential to ensure the correct transfer order of the queue; otherwise, line-balance relationships will be missing.

Activity and line objects are transferred only if they apply to the production version; unrelated objects remain in SAP ERP. Resources are transferred only if they are marked as planning resources (that is, if the capacity planning flag has been set). A resource is automatically created in SAP APO from the resource node proxy object. Once the integration model has been activated, the related transaction data will be sent continuously between SAP ERP and SAP APO in real time. Figure 23 gives an overview of the transfer process.

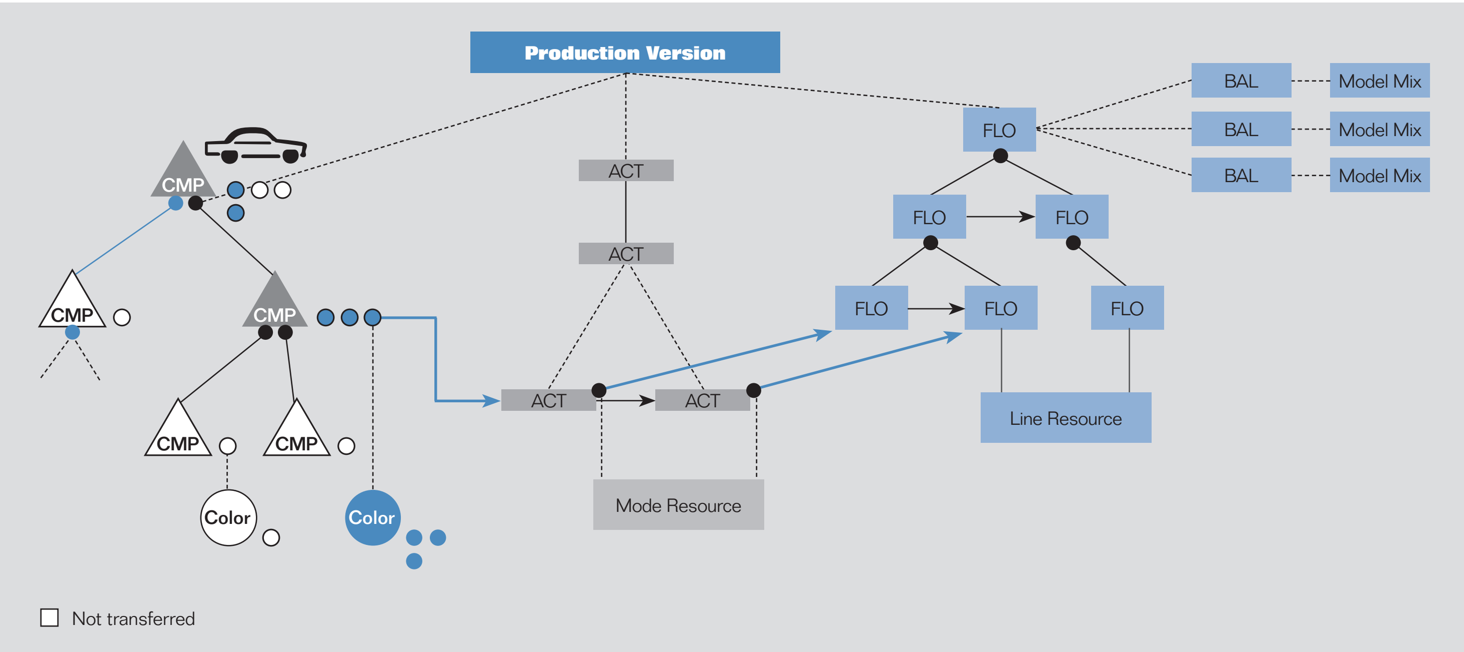

Figure 23: Transfer of iPPE Objects

If iPPE data that has already been transferred is subsequently changed in SAP ERP, these changes must be transferred to SAP APO using the report "CIF: CHANGE TRANSFER IN iPPE," which should be run regularly in the background.

When changes are made to the master data, a change pointer is created. Change pointers are evaluated when the transfer report is run, and they are transferred to SAP APO before iPPE data. After change pointers have been evaluated in SAP ERP, they acquire the status "processed." Once set to this status, change pointers will not be evaluated again. When the status is set to processed, the changes are sent to SAP APO via CIF in the integration model. If there is an error in the queue, these changes will not be updated in SAP APO. Therefore, blocks of iPPE changes should never be deleted from the queue. Additionally, changes to iPPE should only be made in SAP ERP, and then sent via CIF to SAP APO. If the master data is changed directly in SAP APO, there will be inconsistencies between the two.

If new master data (for example, for new components in the PVS or new resources in the process structure) is added to iPPE data that has already been transferred, the master data must be transferred to SAP APO by creating and activating a new integration model. The transferred data can be checked in SAP APO by using similar transactions to those used in SAP ERP.

Once the data is received in SAP APO, additional data maintenance may be required. The SAP APO master data is model-independent. An active version can be maintained together with multiple simulation versions to allow the planning of multiple scenarios for the same item.

From the release SAP SCM 4.1 onward, production data structures (PDSs) must be generated from the iPPE master data in SAP APO. The structure and content of a PDS is optimized for specific applications. The master data is transferred either from SAP ERP or from iPPE (in SAP APO) to the data structure in SAP APO. In combination with SAP for Automotive, it is also possible to transfer master data from iPPE (in DIMP) to iPPE (in SAP APO) and then to the PDS. There is no direct connection between iPPE in DIMP and the PDS. The PDS offers basic services such as reading, generation, and time stamps. The planning applications read the PDS data in order to be able to perform planning operations.

MMP and Sequencing

The objective of an efficient production system for the MTO process is the generation of a feasible and optimal plan for configurable products manufactured in high volumes. It is a plan that considers balanced usage of production resources, early identification of potential bottlenecks, and reliable delivery dates that lead to increased customer satisfaction. Also, line capacity must be utilized efficiently – a challenging task when scheduling across multiple lines.

MMP and (interactive) sequencing in SAP APO enable planning and sequence optimization for configurable products that are produced together on a production line or on several lines. The software is used for takt-based flow manufacturing for configurable products with a high volume of orders. In this type of production, different products are often produced together on one production line or on a line network.

The aim of MMP is to create a production schedule in the medium-to long-term planning horizon. All demands for final products (for example, vehicles) are usually scheduled in daily buckets. Various heuristic procedures are available for dispatching the orders. When used for planning, the software takes into account delivery dates, available capacities (for example, finite line capacity), and any existing restrictions that can also be user defined. It can use various algorithms to determine the optimal allocation of orders to buckets. The software creates period packages that are assigned to the lines on which they are to be processed.

MMP can be executed to plan individual lines or a complete line network. The line network may exist as a series of lines, one after the other, or as parallel lines, which may be used as alternatives. In this case, MMP is executed as multiline planning.

In the short-term planning period, the software uses period packages to calculate an order sequence with exact start and end times, and the transaction takes place in the sequencing area. This order sequence takes restrictions and customer-required dates into account and fulfills certain business aims that may include an equal load of the line segments or takts, a minimization of restriction violations, or a minimization of the absolute schedule deviation. Sequencing is conducted in the short term; the final products are scheduled to individual takts.

By assigning an order to a takt, the order start and end time can be calculated by multiplying the number of takts by takt time. User-defined restrictions help determine the optimal allocation of orders to takts.

Figure 24, below, illustrates the two concepts.

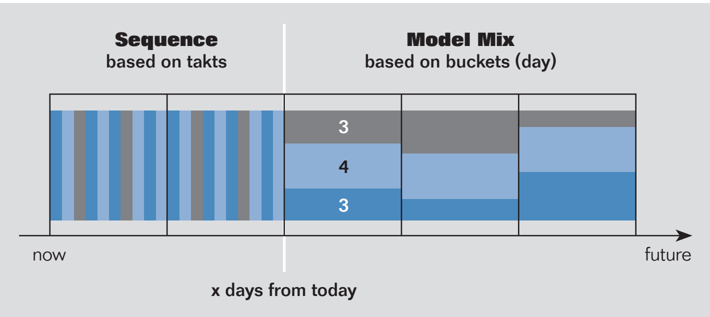

Figure 24: MMP and Interactive Sequencing

With interactive sequencing, planning results can be processed manually in the short term. The orders can be displayed and changed. The software supports the following sequencing-related functions:

- Change sequence manually
- Reschedule orders to an alternative line manually
- De-allocate orders
- Restart an individual procedure
- Display restriction violations and order characteristic values
- Display tracking information for an order
- Start actions from action control for an order

Execution of MMP in SAP APO Using SAP liveCache

A key technology used in SAP APO is SAP liveCache. To improve the system performance, data is stored in RAM instead of in a conventional database, which means that the system can perform planning functions much more rapidly. Data from the SAP ERP side that is processed in SAP liveCache includes iPPE master data and sales-order transaction data. To use this technology, further settings relating to the master data must made in SAP APO (such as restrictions or resources). Once this data is correctly maintained, the planning functions in SAP APO can be used. These include calculation of confirmation dates, model mix calculation of daily buckets, sequencing, and high-volume BOM/PVS explosion for demand planning.

Restriction Types

There are six types of restrictions that can be created in SAP APO. All characteristics use object dependencies (selection conditions). Table 9 below provides an overview of these restrictions.

RESTRICTION	DESCRIPTION
Quantity	Minimum and maximum numbers of products with certain characteristic values that can be built
Spacing	Minimum and maximum break between products with similar characteristics
K in M	Proportion of certain characteristics (representation of characteristics in group of products)
Block	Minimum and maximum group of certain characteristics
Even distribution	Spreading of a certain characteristic across periods (for example, across a day)
Position	Scheduling of a characteristic in a specific takt

Table 9: Restriction Types in MMP

Because you can define multiple restrictions, characteristics may conflict. To determine which restriction is more important, SAP APO lets users "weight" restrictions: hard restrictions must be observed, soft restrictions should be followed if possible. Restrictions can also be defined for different validities (for example, time, version, or location in assignment to a line segment). This enables the creation of a simulated production schedule. Restrictions are maintained using object dependency logic.

Restrictions can be assigned to multiple line objects. It is also possible to assign restrictions to a group. This group can be assigned to a line object later; thus, several restrictions can be assigned to one line.

MMP Run with Solving Algorithms

MMP and sequencing software can use different algorithms to derive the optimum sequence. However, restrictions might need to be managed differently depending on the algorithm used. It is also possible to define one's own algorithms in SAP APO. Table 10 provides an overview of the most commonly used algorithms and their characteristics.

Before MMP software can be run, a procedure package must be defined. A procedure package lists the offset, which specifies the time frame used for sequencing; the sequence; and the time horizon of planning algorithms.

You can use different algorithms in the same planning procedure with different time frames. For example, users can plan orders for the near future using the genetic algorithm; orders for the next two weeks – including those with single orders – using equal distribution; and orders for next three months that only accumulate in variants using a customer heuristic.

Interactive Sequencing

MMP software determines the optimal production sequence in the background. Other than reviewing the log, there is not much more users can do with the transaction. But interactive sequencing – as the name suggests – allows users greater visibility and flexibility, and the ability to do the following:

- Drag and drop orders to remove them from one slot and assign them to another slot

ALGORITHM CHARACTERISTIC	GENETIC ALGORITHM	LINEAR PROGRAMMING	EQUAL DISTRIBUTION	PERCENTAGE SMOOTHING	PURE ALGORITHM
Line	Single/Multiple	Multiple	Single	Single	Single
Restrictions Allowed	All	Quantity, Spacing	Quantity, K in M, Spacing, Position	None	None
Capacity	Finite	Finite	Finite	Finite	Infinite
Order Size	1	1	1	> 1	> 1
Description	Best of Breed	Solving of Equation	Even Mix	Match Capacity	MRP

Table 10: Common Algorithms for MMP

- Firm up orders that are not to be rescheduled by automatic planning
- Search for orders with certain characteristics
- Run algorithms for specified shifts
- Choose the characteristics to be displayed:
  - Orders for a selected range of days and/or shifts
  - Valid restrictions within the period
  - List of order sequence
  - List of unscheduled orders
  - Bucket grouping and totals

Restrictions and characteristics can also be visualized in interactive sequencing software to enable efficient and concise planning. While MMP software runs in the background, the sequencing results can be manipulated by the user in the foreground. MMP software requires planning procedures, while sequencing software requires the user to enter a date range. MMP software plans against the entire line net, whereas sequencing software only considers the planning segment. It should be noted that there can be only one new planning segment per line.

Because of the increased graphical functionalities of sequencing software, limiting the date range is recommended. The number of orders planned increases with the date range, which can affect system performance. In general, then, sequencing should only be done for a short-term horizon when detailed planning is possible.

Multiline Factory Layout and MMP

This section references the section titled "Factory Layout and Line Design," which discusses multiline structures. A line area is defined at the modeled line net and is used to specify a valid path across certain line objects that a product has to take during the manufacturing process. This is necessary if a vehicle can only be produced on specific lines. Sometimes a product can be produced not only on one specific line, but also on any of several lines that have the same function. During planning, you need to be able to define which of the alternative lines will be used to produce the order for a particular product. Now, there is a new node type, "group of alternative lines," that can be used to group together alternative lines. This node type enables the manual movement of an order from one line to an alternative line in interactive sequencing. Similar to a line segment, work centers can also be grouped together if the vehicle can be produced in several alternative work centers.

Based on capacities and restrictions, MMP determines which line the order should be built on. The line assignment can be changed manually for orders that have already been planned or started. You can switch lines by changing the active mode in the corresponding order activity. All subsequent processes then receive their data based on the active mode.

Alternative work centers are functionally identical to line segments but realized with the use of alternatives. Hierarchical relationships are built from the alternative downward. Relationships between lower-level nodes can exist only if these objects are assigned to the same alternative segment. Alternative work centers are below the line level and are therefore not planned (in contrast to alternative lines). One of the alternative work centers has to be identified as the default work center for planning purposes. Backflush processing determines which of the alternatives was used for a certain order; therefore, there needs to be a reporting point at the end of each alternative. Depending on the selected alternative, the components are taken from the corresponding supply area.

If the line net is defined as a multiline hierarchy, then you can restrict the parts of the line net that a particular vehicle can travel along. You do this by creating product-dependent "part of line nets" to which lower-level line objects are allocated. Part of line nets are specified in the production version. Even with multiple part of line nets, all products must be planned simultaneously without ignoring the situation of the specific product.

Objects that contain all lines can be planned jointly and as product independent, whereas objects that represent the situation for a specific product must be planned as product dependent.

During MMP, capacity profiles and spacing (quality restrictions) assigned to lines or groups of alternative lines further limit the building possibility on these lines for certain orders. Some restrictions have a so-called "conversion factor" that is used to convert a spacing restriction into a quantity restriction using the takt and shift times. Restriction types that can be converted are "spacing," "K in M," and "position."

The line net is decomposed into possible paths. Even though restrictions are assigned to only one line, this line can be assigned to several paths. Different products can run only on certain paths, depending on their production versions. Based on the part of the line net, SAP APO determines all the possible paths a vehicle can take through the production line. Considering the alternative line groups, one vehicle can take multiple possible paths. At this point, a linear program assigns orders to the paths while respecting the restrictions and production versions. MMP is obtained by adding the paths' loads segment by segment; paths are consolidated back to the original line to determine the capacity load on each line. Orders are allocated to lines based on day or shift buckets, thus completing MMP. Interactive sequencing is then run to convert from buckets to individual takts in the plan.

Again, while MMP considers the entire line net, interactive sequencing only plans against the planning segment. The orders assigned to a particular bucket are arranged in a specific sequence; the bucket size can be for a shift or a day. Because the model mix uses aggregated spacing restrictions, it should be possible to obtain a feasible sequence for bucket orders. The sequence is defined in the planning segment, and it can be manipulated later with interactive sequencing. The order sequence derived in the planning segment is transferred to the preceding and (or) following lines; it is only possible to have one planning segment per line net.

It should be noted that only restrictions from the planning segment are considered during sequencing; restrictions for all other lines are ignored.

RPM

In an MTO environment, almost no orders are identical, and the customer may want to change the configuration during the production planning phase. This is especially true for the trucking industry, where orders are received early, but many changes are made up to the last possible moment. Short-term engineering changes due to technical requirements or production costing may also occur. Problems can also arise if a supplier cannot deliver enough parts.

Given the significant variability of orders that are individually configured by customers, the high volume of data, the complex structures, the frequency of engineering and customer changes, and the potential problems with supply, it is important to be able to respond quickly and flexibly to change. The product structure (for example, in the form of a BOM) is a key piece of data in this process, and the ability to achieve a fast explosion is essential. Besides a high-frequency and fast MRP, it is also necessary to use precise and current data together with fast reporting tools and business functions. The only way to achieve customer satisfaction is to respond rapidly to order and engineering changes and address changes forced by issues on the supply side flexibly and collaboratively.

The RPM, or rapid planning matrix, is a product-related database that is stored in SAP liveCache for SAP APO. It provides two matrices for planning: a component variant matrix for calculating the required components, and an activity matrix for calculating the required activities.

The RPM is the basis of a new form of production planning in SAP APO. It is used for products with many variants and large numbers of orders to quickly determine requirement quantities and dates for the components of a product. It also lets users specify whether the software needs to generate an activity matrix during the planning run.

Overview of the RPM

MRP with the RPM in SAP APO is based on the master data from iPPE. Any changes made to master data, including those made to the PVS, the line resource, or the order sequence, are automatically transferred to the RPM.

The planning matrix includes the following:

- Data from iPPE (PVS, line, and process structures)
- Data for the line resource, such as takt time or shift sequence
- Data from orders planned for the product in SAP APO, such as the start and end dates for the order
- Information on which components are needed for which order (= *setting the crosses*), determined by exploding the PVS and taking into account object dependencies in iPPE and the validity data maintained in ECM

The following activities require data from the RPM:

- Determination of the component requirements for each order and each defined period for further planning in SAP APO and SAP ERP
- Generation of order BOMs for planned order management
- Generation of order BOMs for backflush at reporting points
- Transfer of data from the matrices as the basis for sequencing
- Forecasting the delivery schedule, creating a just-in-time (JIT) delivery schedule, issuing a sequenced JIT call

The following example illustrates the type of bottleneck problems that can occur in MRP and the advantages of planning with an RPM:

A typical maximum BOM for a car has 40,000 components, including all historical changes. An exploded customer order consists of 2,000 components of the maximum BOM selected, which results in storage of 60 GB of dependent requirements in the MRP database in SAP ERP in relational form. This data must be read and written during an MRP run. The order explosion must consider all historical changes to a component variant, resulting in 1.2 billion checks of effectivity parameters and, in the worst case, 1.2 billion checks of selection conditions. The alternative is to model this data in iPPE and use SAP APO, which stores data in RAM instead of on a hard drive (see the section on SAP liveCache for more details) and uses an optimized form for the data that requires very little memory and allows for object-oriented access. The matrix representation in this case allows for simultaneous explosion of all orders instead of explosion on an order-by-order basis.

Classic MRP Versus RPM

The flexible MTO process described in this paper also relates to the RPM. There are various options for planning methods to consider, depending on the need for factors such as rapid planning, highly configurable products, or integration back to standard SAP ERP. Companies can choose a combination of planning methods. Figure 25 provides an overview of the most common methods.

In order to use the RPM, the product data must be modeled in iPPE as a PVS. However, with release of DIMP 4.7 it is possible to convert an ERP BOM into an iPPE PVS. It is also possible to do the reverse.

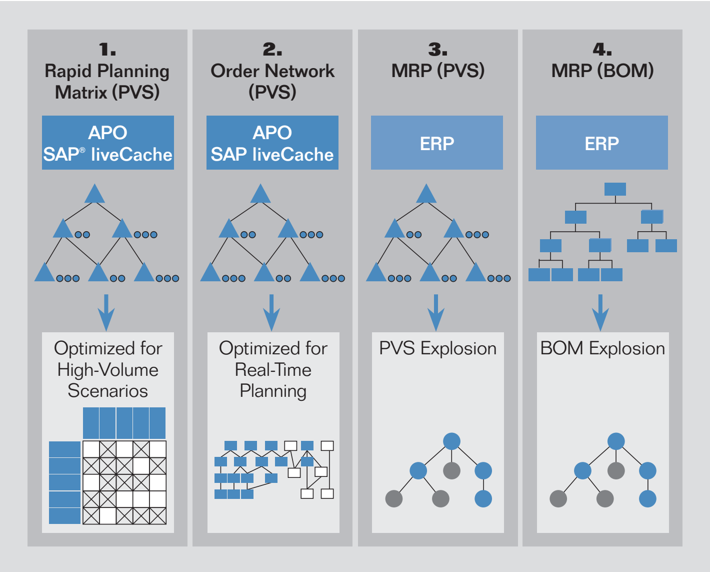

Figure 25: Alternatives in Requirements Planning

The RPM is generally better suited for configurable products with a high order-production volume, a standard product group, and manageable engineering content, which includes most vehicles and components in the automotive industry. The strengths of the RPM are in high-volume backflush and sub-daily planning. The issues concerning the RPM and its structure are discussed later.

Because the size of the matrices in SAP liveCache is almost exclusively determined by the number of lines representing components or activities, the RPM is at its most impressive when dealing with a high volume of orders. On the other hand, if the component list becomes too complex – especially with product structures that have a high number of engineer-to-order (ETO) or configure-to-order (CTO) components – the RPM is not as efficient as other planning methods. Relatively small production volumes reduce the efficiency further.

The same issues apply to hierarchical product structures, for example, those involving several phantom assemblies. Since the RPM explodes the maximum structure of products or activities in a first step and calculates requirements afterward, it also explodes alternative subnodes that will be excluded in production due to the choices made. These nodes may not be exploded by a standard top-down explosion; this makes the standard top-down explosion more efficient for the explosion of complex products with many hierarchy levels and several alternative choices on each level.

If the iPPE structure is very complex and offers many possible alternatives and (or) the order volume is rather low, a top-down single explosion in an order network might be more appropriate. This second method has the advantage of speed through SAP liveCache, but avoids the possible lack of performance caused by a very complex product structure. Exploding the product and activity structures top-down makes it possible for users to exclude nonrelevant structure nodes, depending on the individual sales order.

A third method is to use standard MRP functionality in SAP ERP. MRP is best used in scenarios with low order volume, nonconfigurable products, diverse product groups, and a large amount of engineering content – a common situation in the aircraft and industrial machinery industries. The strengths of MRP lie in the ability to handle configurable ETO products, net change planning, and multilevel explosion. Since standard MRP takes place in SAP ERP, no advanced planning system such SAP APO is needed. Therefore MRP is particularly suitable for planning B and C subcomponents of a product.

MRP is possible using PVS or BOM structure, and a converter exists to transform each of these structural types into the other.[7]

7. Going forward from release DIMP 4.7, the conversion of an iPPE structure in a BOM structure is possible; conversion of BOM structures into iPPE structures was already possible with release DIMP 4.6C.

The main function of MRP is to guarantee material availability; it enables companies to procure or produce the requirement quantities on time both for internal purposes and for sales and distribution. This involves the monitoring of stock and, in particular, the automatic creation of procurement proposals for purchasing and production. In the scenario described here, "requirements" means concrete customer requirements (external or internal); there is no sales forecast in the scenario. The result is the independent requirement, that is, the requirement for finished products, assemblies, subassemblies, or replacement parts. The result triggers MRP.

In order to cover these requirements, MRP software calculates procurement quantities and dates, and plans the corresponding procurement elements, that is, the planned order or the purchase requisition. These are internal planning elements that can be changed, rescheduled, or deleted at any time. If a material is produced in-house, the software also calculates dependent requirements – the quantity of components required to produce the finished product or assembly – by exploding the BOM. These planned procurement elements are then converted into exact procurement elements, that is, production orders and purchase orders, respectively. The in-house production order contains its own scheduling procedures, capacity planning, and status management. Cost accounting is also carried out via the individual production order. Materials that are produced externally trigger purchasing procedures. The quantities made available by production or by external procurement are placed in stock and are managed with inventory management software.

SAP liveCache

SAP liveCache is a database engine based on SAP database technology for managing complex objects in SAP software, such as SAP APO and the SAP Product Lifecycle Management (SAP PLM) application. SAP liveCache guarantees the best possible performance and is useful in situations where large volumes of data must be permanently available and modifiable. It is an enhancement that was made to the relational database in SAP software to enable the data structures and data flows (such as networks and relationships) to be mapped more easily and effectively. SAP liveCache is object-oriented and, unlike MaxDB, works with its data only in the main memory of the database system, if the system is configured optimally.

SAP liveCache has data positions for master data, transaction data, planning results, and BOM explosions. It fulfills technical requirements such as fast read/write access, needs very little memory, and can be accessed with modern object-oriented (OO-type) operations. It can also work with multiple business and planning functions. Figure 26 provides an overview of data handling in SAP liveCache.

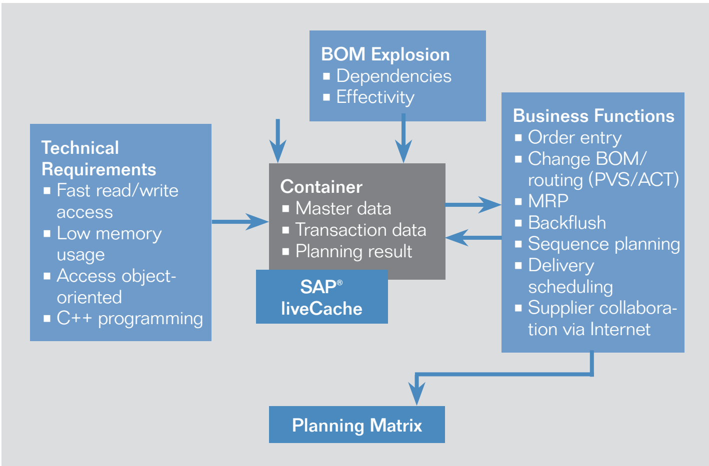

Figure 26: Data in SAP liveCache

Structure and Reading of the RPM

The rows of a planning matrix contain all the components of a product, which the software determines from component variants in the PVS for the product. Or, it can contain all the activities, which the software determines by exploding the process structure. The columns contain the planned orders for the product that are lined up in SAP APO. The use of a component or an activity in an SAP APO order is indicated by an "x" in the appropriate row of the planning matrix. The structure of a matrix for calculating components can be seen in Figure 27.

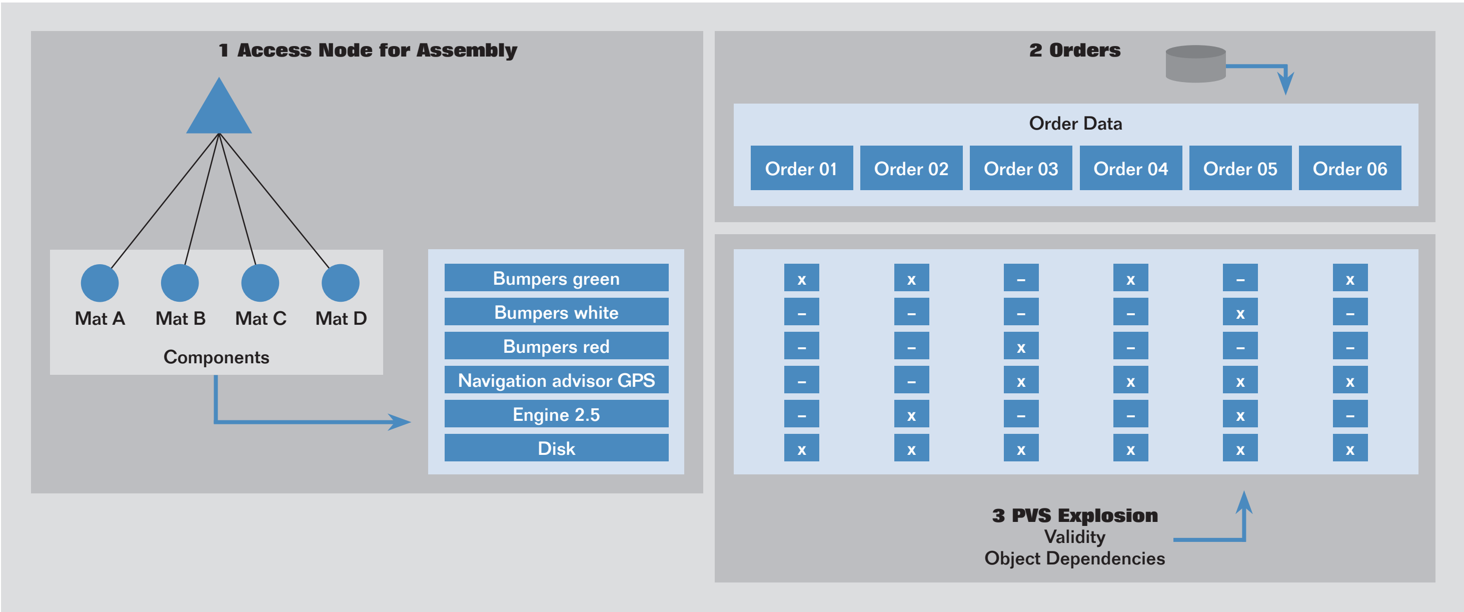

Figure 27: Contents of the Logical Matrix

In the first step, the assembly view of the PVS is converted into a flat list of master data that includes material numbers, quantities, selection conditions, and effectivity parameters. In the second step, the assembly orders are included (due date, quantities, and configuration). Explosion of the BOM/PVS represents the third step.[8]

The RPM for determining components consists of data from two matrices:

- The characteristic value matrix is a way of storing object dependencies for the individual orders in SAP liveCache. The rows of this matrix contain all possible characteristics. The columns contain configurations from the orders.
- The component variant matrix contains all components for the product (corresponding to the super BOM) and the order data.

Reading the component matrix vertically allows for the determination of components per order, the BOM, and the component requirements. Writing to the matrix allows for MRP, backflush, and impulse activities, as well as sequencing activities and the generation of sequenced JIT calls.

Reading the matrix horizontally enables the determination of all component requirements. Reporting functionality includes a stock-requirements list, coverage calculations, delivery scheduling, and pull lists. Time buckets can be created for component requirements. They represent input for MRP requirements including SAP APO orders (for example, purchase orders) and delivery schedules in SAP ERP (only daily requirements). The size of a time bucket is variable; short-term horizon buckets include more data than those with a long-term horizon.

8. One cell in the matrix compiles to one bit; 30,000 orders and 40,000 components make up about 350 MB.

When activities also need to be determined, the software generates another matrix. The activity matrix allows the calculation of actual resource requirements per workstation and aggregates all activities that are carried out at a station. Actual working hours can be matched with available working hours. The production scheduler can adjust resource availability to the requirements. The necessary information for the activity matrix comes from iPPE routing. Several further activities are integrated into the matrix including backflushing (posting of all performed activities and capacity reduction), controlling (value of all activities per vehicle and resource capacity), and model mix (material matching of necessary activities against resources).

As mentioned earlier, the best RPM performance concerning characteristics can be achieved by modeling one value ("yes" or "no") for each characteristic.

The component and activity matrices show the exact requirements per order. Through the assignment of activities to the line, the matrices can also determine exactly when these inputs are required. If a vehicle needs a certain component, these inputs (resource and material) will be required when the vehicle reaches the appropriate workstation.

Production Execution and Control

After all production activities have been planned, the actual production process can be triggered. To have an efficient production process, you must be able to control the process completely at all times. Production activities must be tracked and the controller must have the ability to stop or change processes. In addition, this portion of the process includes several backflush processes as well as cost settlements and other postings.

The following section deals with the execution and monitoring of the actual production process, focusing primarily on two main aspects of the process: the action handler, and confirmation and backflush activities, including cost settlements.

The Action Handler

The action handler is a component of SAP APO and is used for automatic or manual execution of functions before and during production. It links the planning functionality in SAP APO with an external production control system (PCS).

The action handler is usually used in repetitive and flow manufacturing, but it is also possible to use it in shop-floor production. In the scenario examined in this paper, the action handler is used together with iPPE, but it is also possible to use it without iPPE.

There are two types of action handlers: an automated action handler that is used during production, and a manual action handler that is used before the actual production process. Generally, these are not used separately, and in practice, the production process is better optimized when both are used, as follows:

Automated Action Handler

The automated action handler is used for recurrent production steps. The software carries out the same actions several times (for example, printing of documents, production tracking, and backflushing). In this process, the software automatically carries out one or several actions with all planned orders as soon as the PCS reports that planned orders have reached a certain action point depending on an event. The number of actions that can be processed at any time can be increased by installing the necessary hardware. A special function of the automated action handler is production tracking, which saves certain order-specific information at specific action points during production.

Manual Action Handler

The manual action handler should be used when the user is processing steps for single orders in SAP APO. The software provides a user-friendly environment that lets users prepare for the production process by, for example, carrying out available-to-promise (ATP) checks for components, releasing orders, and so on. Use of the manual action handler is only possible together with iPPE. Using the manual action handler during production preparation allows for the selection of individual planned orders.

In addition, you can do the following:

- Manually carry out stand-alone actions at any point in the planning process (for example, send messages or print documents)
- Manually carry out actions within defined multidimensional action networks[9]

The manual action handler is integrated into planned order management and the sequence schedule of MMP.

SAP software enables several standard actions that can be changed according to specific needs. It is also possible to define or program your own actions. Figure 28 provides an overview of the composition of the action handler.

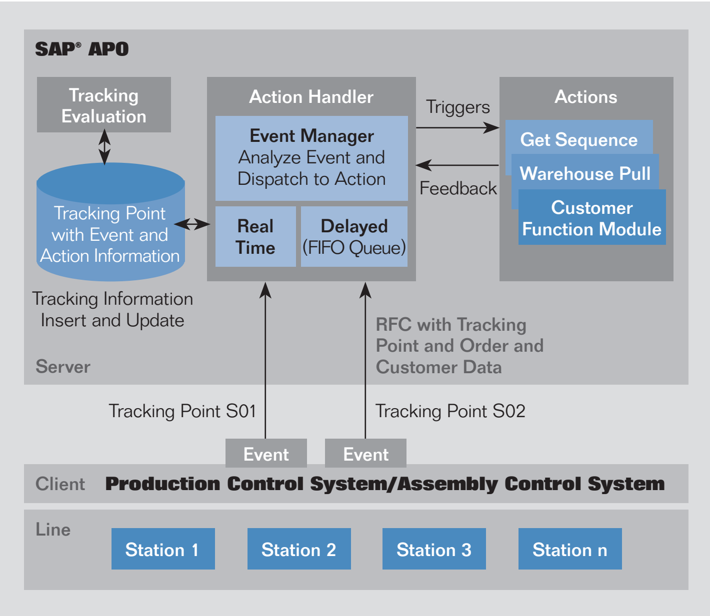

Figure 28: Functional Structures in the Action Handler

Integration and Action Points

An action point is a point at a production line or a work center at which an action can be triggered automatically in SAP APO depending on an event. Table 11 lists the possible types of action points.

ACTION POINT TYPE	DESCRIPTION
Obligatory	Reporting of the action point is obligatory.
Optional without retroactive execution	Reporting of the action point is optional.
Optional with retroactive execution	Reporting of the action point is optional. If the action is not reported the software retroactively carries out the actions assigned to it when the succeeding action point is reported.

Table 11: Action Point Types

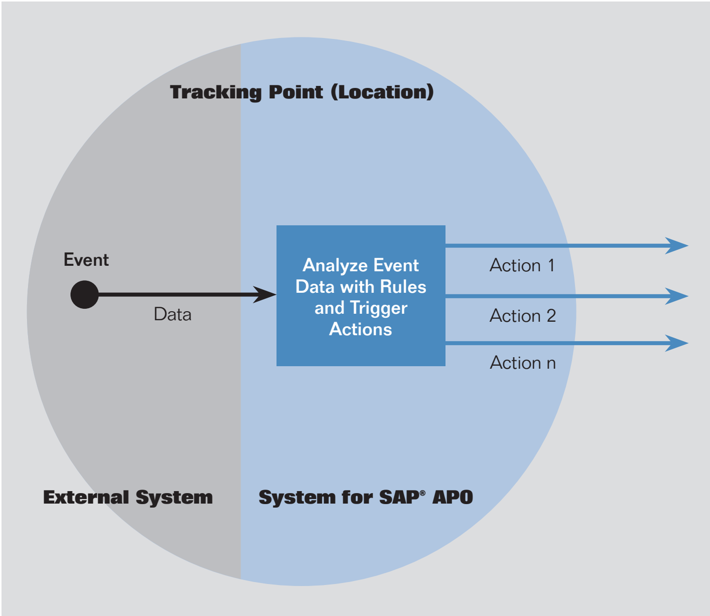

Figure 29: Action Points

9. An action network is a multidimensional object in which the business-related dependencies of actions are defined. Action networks are assigned to planned orders and allow for mass processing.

The action points of the automated action handler can be the same as the ones in iPPE, so it is possible to use them as reporting points for backflushing. The software automatically copies all action points that are created in iPPE to the master data of the action handler.

An action is a business operation that refers to processes that take place in production planning and control, and it is carried out automatically by the software or manually by users. An action consists of one or more functions. When an action is called, the action handler individually processes these functions in the sequence determined.

There is a flexible link between events and actions: the triggering of an action can be made dependent on a start condition or can be triggered at any time. For example, users can define a workflow that models which action will be triggered by a certain event. It is also possible to set up the software to always trigger the same action for a defined tracking point. There are two types of events: real-time events and delayed events. They are handled in the event queue on a first in, first out (FIFO) basis.

From a technical perspective, the action handler has just one generic interface. Users can define additional actions without having to make code changes, and process a high volume of events (for example, 50,000 events per day).

An action point can have several actions assigned to it. For each coupling, it is possible to define a responsible person. The sequence of actions is not predetermined, so it is possible to run each action independently of others. A single action can have different parameters at several action points.

Using the action handler, the user can modify orders by adjusting the order start time, changing the activity status with a defined action (if factory layout is used), deleting the order, or undoing the allocation or scheduling of the order from the production line. It is also possible to assign orders to an action net or to switch orders from one line to another. And you can perform tracking and backflushing using the action handler. These issues are covered in the next section.

Finally, the action handler includes a reporting function that triggers the dispatch of notifications or e-mails.

Using the Action Handler with Other Software

The display of production tracking information within planned order management software enables users to check the production progress of selected planned orders and follow up on errors in the production process. In addition, companies can use business add-ons to save tracking data with additional customer-specific data included. The captured tracking information contains a full history of all events including the tracking point, a time stamp, and the production order. This data can be aggregated and evaluated to help address, for example, quality problems or product recall. Users can also calculate WIP quantities.

In repetitive manufacturing with iPPE, the action points are linked to elements of the line structure. Alternatively, action points can also be assigned to the mode of activities in the process structure (for example, in shop-floor production). Maintaining action points in iPPE is advantageous because the line structure of iPPE automatically determines the sequence of action points. Predecessor and successor relationships for action points must not be specified because they are already defined by the line structure and relationships of iPPE activities. The software automatically determines the resource for the action point by using the element of the line structure to which the action point is assigned; this means the resource does not need to be specified via a parameter. Therefore, action points can also act as reporting points for backflush, thus reducing the goods movement load.

If a line change occurs, it means that the vehicle was planned on one line but is manufactured on another. This change is automatically recognized when the vehicle passes the corresponding reporting point or tracking point. In this case, the components and activities of the matrices are automatically adjusted via the change in production version, including the change of RPM, and a new explosion of the product structure, and the correction of requirements.

Action handler functionalities are also integrated in interactive sequencing. For example, it is possible to access tracking information, switch activity between alternative lines, and list the interactive actions applied to marked orders.

Confirmation and Backflush

Backflush functionality is used in environments where there is a high volume of orders for small order quantities – often, only one piece per flow as described in this scenario. This functionality was developed specifically for this high-volume scenario, which is particularly common not only in the automotive industry, but also in high-tech industries.

Backflush can be carried out very quickly due to both a new link to SAP APO – where the creation of backflush is separated from the processing of backflush data – and to the greater separation of logistics and controlling functions.

Backflush is created in SAP APO. Subsequent processes – that is, the posting of goods movements and production activities – are carried out separately in SAP ERP.

A backflush can only be carried out for a reporting point that has been defined in iPPE. Therefore, the product structure of the materials to be backflushed **must** be maintained in iPPE; the software does not support the classic BOM and production process model. Production backflush is only possible for repetitive manufacturing and for shop-floor-oriented manufacturing. A direct link exists to periodic product cost controlling functionality via the product cost collector (see the next section for further details).

The following is possible in production with backflush functionality:

- Backflush can be executed for MTO repetitive manufacturing and make-to-stock (MTS) repetitive manufacturing, as well as for shop-floor-oriented manufacturing. However, this scenario only deals with MTO repetitive manufacturing.
- Backflush at reporting points is possible in MTO production.
- Synchronous and asynchronous goods movements are posted separately to speed up processing in SAP ERP.
- Goods receipt in the MTO procedure is evaluated on the basis of material consumed, labor executed, and overhead. This significantly improves performance and enables the software to determine goods receipt value.
- WIP can be calculated in controlling software.
- Backflushes can be archived via an archiving object.
- Backflush data is updated in the SAP NetWeaver Business Intelligence (SAP NetWeaver BI) component where it can be evaluated.
- Backflush functionality can be used for products with product interchangeability.

Backflush functionality also supports iPPE production with phantom assemblies or by-products.[10]

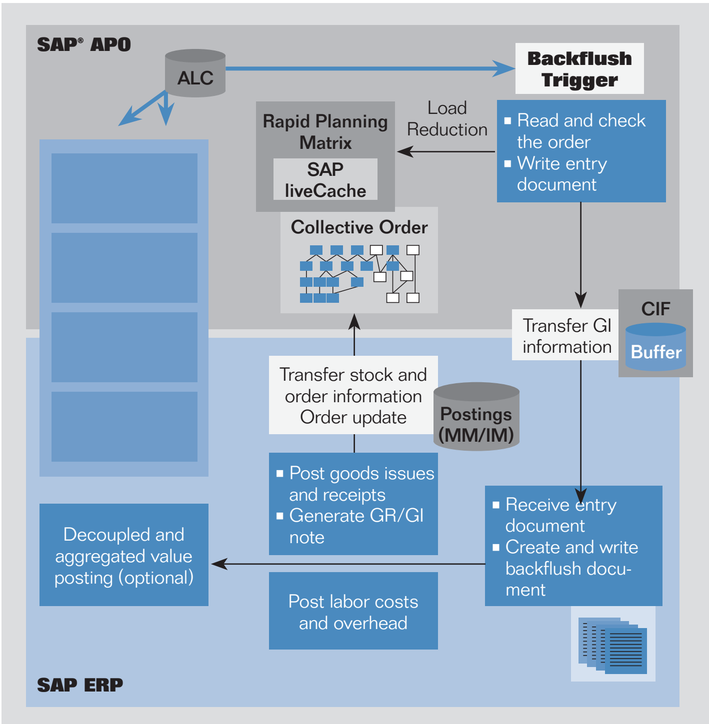

Figure 30: The Backflush Process

10. Integration with other components, such as the most recent software for HR, is carried out step-by-step and is not yet available.

With the backflush profile in SAP APO, users have flexible access to the backflush transaction, as well as the option of triggering a backflush via the action handler. When order processing takes place in SAP APO, capacities are immediately reduced and inventory management information is transferred to SAP ERP.

Several goods movements take place in SAP ERP:

- All goods receipts and GIs of synchronous materials are posted immediately.
- GIs of asynchronous materials are periodically aggregated and posted.
- Processes can be distributed to several servers.
- An application log can be used in place of a document log.

Failed goods movements end up in the corresponding post-processing area along with cumulative and individual records including those for goods receipts.

Finally, backflush data is transferred to SAP NetWeaver BI and archiving functions for backflush tables can be run.

Several date-specific prerequisites that must be maintained in SAP ERP are required to perform an actual backflush. iPPE data must be maintained and a production version must exist, because it is used to determine the cost collector for cost settlements. Also, a repetitive manufacturing (REM) profile must be entered in the material master (for example, movement types, batch, and stock determination). The components with synchronous GI, as well as those with asynchronous GI, must be determined as well. Classes and characteristics, and sales orders with assigned characteristic values, must be created. Finally, a product cost collector must be created and set as “SAP APO cost collector” in the first backflush.

Data from iPPE and production versions in SAP ERP is transferred to the correspondents in SAP APO via the CIF interface. Material master data is transferred to the product master in SAP APO, and planned orders are created from transmitted sales orders.

Orders in the RPM in SAP APO are planned production orders and are pegged to sales orders (MTO) or forecast orders (MTS). There is no quantity differentiation within the matrix – exactly one column is created per order. Planned production orders must always be split to the quantity of one if the RPM is used. Otherwise, the complete planned production order must be backflushed.

Backflushing in SAP APO is always carried out for a certain reporting point. However, reporting-point structures can be changed during production. One order always refers to exactly one reporting point structure. A reporting point can be defined in line design at the beginning and (or) the end of a line segment. Unlike lines, activities contain no reporting-point definition. It is only possible to reverse an action in a document-neutral way by using the opposite movement direction during posting.

Valuations in controlling for WIP and good receipt (GR) cost estimates are based on actual postings. When an order has passed a reporting point, the matrices are updated to reflect the inputs used for these orders. While consumed requirements are shown as **0** or **+**, open requirements are shown as **x** (see Figure 31).

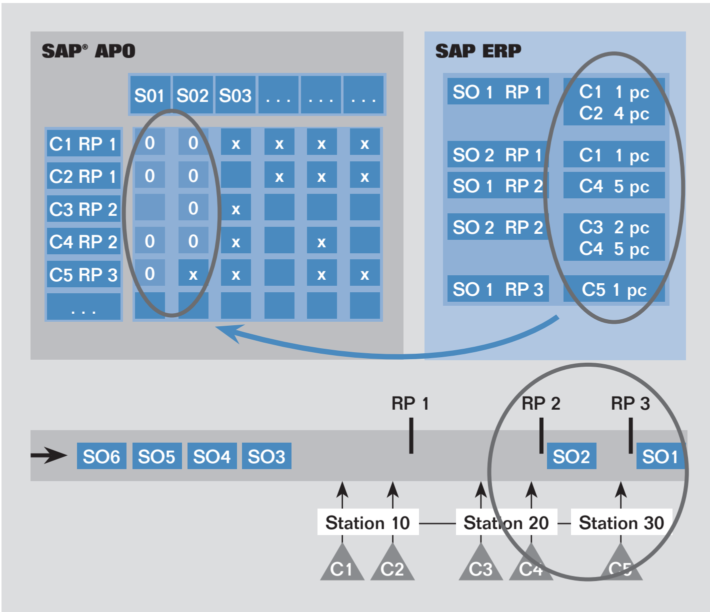

Figure 31: Backflush of Orders

Backflush data is sent from SAP APO to SAP ERP for posting in financials (FI) and controlling (CO) software. Because the vehicle is still in production at this time, component costs are allocated to WIP. The material price is maintained in SAP ERP. Upon goods receipt, the value of components is transferred from WIP to the finished goods area (synchronous posting). This is accomplished by the posting of a credit to the WIP account. In case of scrap, adjusted entries need to be made to reduce the WIP account and increase the scrap account.

Backflush Process Flow in Two Steps

Production backflushes, which are sent from SAP APO to SAP ERP, contain components and activities to be posted. Components can be posted either synchronously or asynchronously, whereas activities are always posted asynchronously (transaction *PPCGO*).

Synchronous posting means that goods movement is posted immediately upon the transfer of backflushing data from SAP SCM to SAP ERP. Goods movement or production activity that is not posted immediately on transfer is posted asynchronously. Backflushing data from SAP SCM to SAP ERP is initially recorded in a buffer in the database. Processing and posting of data is triggered later by a report.

The indicator **synchronous posting GI** shown in the product data master in SAP SCM determines how a material is posted. All GRs and GIs of synchronous materials are posted immediately (that is, synchronously) irrespective of the indicator in the product master software. GIs of asynchronous materials are periodically aggregated and posted.

When backflush takes place in a high-volume production process the number of cost collectors increases significantly, which can lead to a deterioration in performance. This occurs because material documents must be created for each cost collector even if the components are the same. This step is necessary for the postings to financials and controlling software. To avoid deterioration in performance, the backflush can be executed in two steps. This method of processing is advantageous because it keeps logistical data consistent even if the FI and CO data is posted only once a day. In two-step production backflush, the requirements are adjusted in SAP APO after the first step.[11]

Two-step production backflush works in the following way:

1. The system reads all open backflushes and corresponding components. The quantities of components are grouped according to posting date. The software posts components without reference to a product cost collector from a non-MRP storage location. Production backflushes are updated and goods movements are posted. At the same time, the product cost collectors and information about the components is stored in a new table. Then backflush data is updated in SAP APO.
2. The components are grouped according to posting date and product cost collectors. Goods movements are posted per product cost collector (for example, once a day). The data in the FI and CO area is updated.

If errors occur in either of the steps, postprocessing of the production backflushes is possible with the transaction *COGI*.

---

11. In order to execute the backflush in two steps, the backflush profile must be maintained properly. Standard procedure includes the transfer of all stock from SAP ERP to SAP APO. In order to process the production backflush in two steps it is necessary to define a dummy storage location that is not MRP relevant. To avoid the transfer of stocks for this storage location to SAP APO, a user exit must be implemented. Further information on this can be found in SAP note 496020.

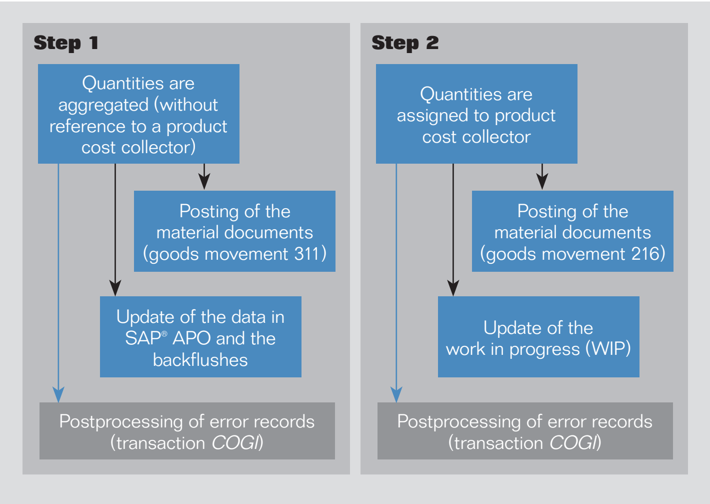

Figure 32: The Process of Two-Step Backflush in Production

The advantage of the two-step production backflush is that logistical data is already updated before the data in FI and CO software is posted. Goods movements are aggregated before they are posted, thereby improving the performance of the system. For example, assume that 100 assemblies made up of 500 components are produced every 30 minutes, and the posting results are quite different depending on the backflush. Using one-step production backflush, the software creates 100 material documents every 30 minutes with 500 items each. This leads to a total posting of 50,000 line items. In two hours, 200,000 line items are posted. In two-step production backflush, only one material document with 500 line items is created every 30 minutes. After two hours the GI is posted for each product cost collector from the non-MRP relevant storage location. This results in a posting of 50,000 line items; that's 52,000 line items in total compared to the 200,000 line items in the one-step production backflush.

Cost Settlement and Postings

Profitability analysis can be performed in SAP ERP using several resources. The postings from the sales and distribution (SD) side are usually the most important source for profitability analysis. For the cost-accounting profitability analysis, two sources of data are transferred from the SD side: sales-order changes and billing data. For the posting-date profitability analysis, two sources of data are transferred from the SD side: GI and billing data. Costs from other areas of CO can be settled periodically via settlement, assessments, or activity allocations to changeover in profitability analysis (CO-PA) objects (see Figure 33).

As discussed in the previous sections, a product cost collector must be created for each vehicle variant. All production activities for this variant are posted against the corresponding cost collector. Based on settlement rules, the costs can then be allocated to other financial accounts.

In this MTO scenario, vehicles are managed individually by sales order. Each sales order stands for a unique vehicle configuration. After production, the inventory is managed as sales order stock. The cost collector is generic at the material level. That means that all vehicle costs (for the same material) are captured in the same cost collector. As a result, vehicle costs can only be analyzed on a periodic basis and not for an individual vehicle.

Further information on cost calculation and valuation can be found in the following sections.

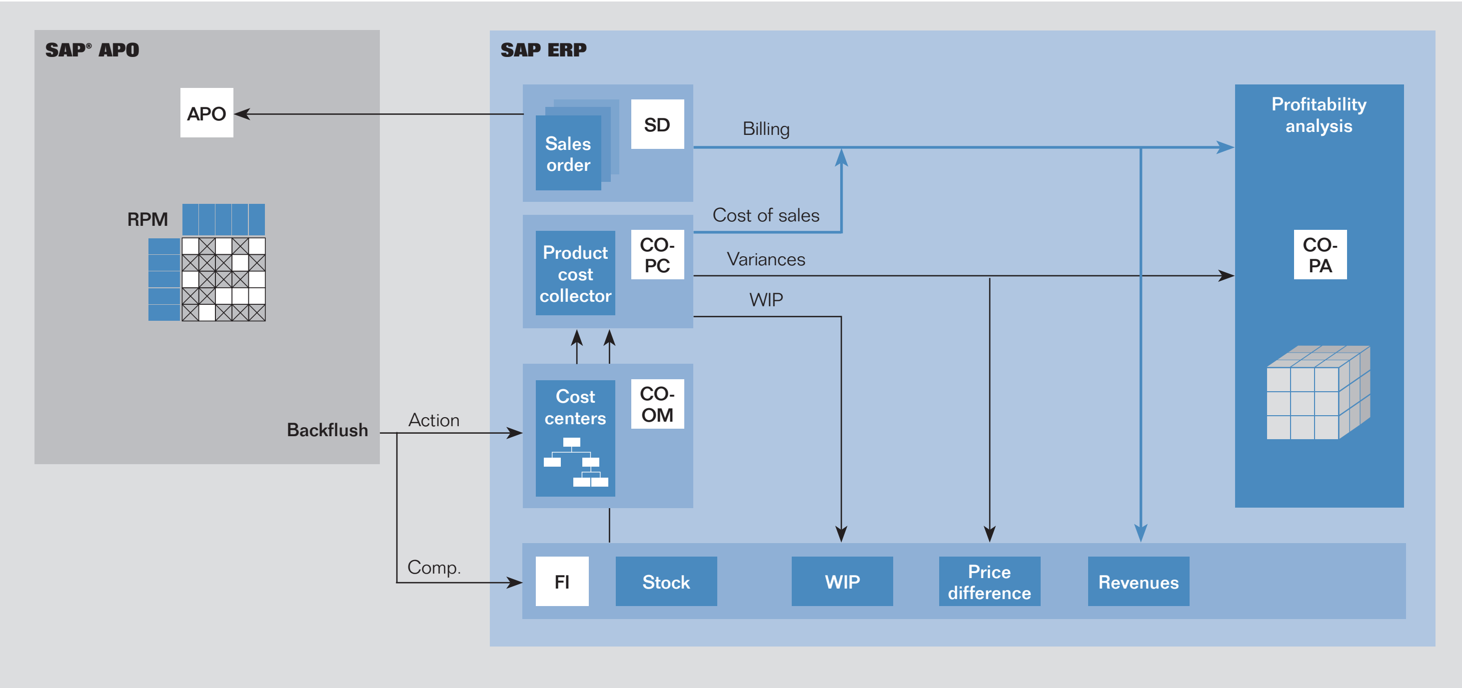

Figure 33: Value Flow in Controlling

Production Cost Controlling

In contrast to product cost planning in SAP ERP, no BOMs and routings are costed in this scenario. Instead, only iPPE master data (such as variants and modes) is costed. In the cost object controlling area, costs are analyzed using quantity-based product cost collectors. Quantity-based valuation is an approach that is only used in SAP software for discrete manufacturing. With this approach, the product cost collector is debited and credited with postings from SAP APO through an interface. The management of reporting points here differs significantly from the approach used in SAP ERP. The assignment of product cost collectors to cost object hierarchies does not apply in this case.

Production cost controlling functionality in SAP APO enables users to determine stock values at the time of GR, based on the confirmed quantities for components and activities, and on the progress recorded in the software. The functionality enables users to determine WIP status, scrap for sales-order-specific costs, and variances (see Table 12).

A cost collector must be created with the controlling level *material/production plant/planning plant/production version* for the configurable material. For the calculation of WIP, a results analysis key and a variance key must be assigned to the product cost collector.[12] Valid cost estimates should exist for the input components. Otherwise, the prices in the material master records are used. If activities are included in confirmation and costing as well, a link between the iPPE resource (or the mode) and overhead cost controlling functionality must be established in iPPE.

12. SAP recommends using the results analysis key *0000005 (quantity-based valuation)*. The assignment can't be changed once the WIP has been calculated for the first time.

The daily production cost function enables users to determine the short-term production cost for the product cost collectors used in the confirmation in SAP APO independently of the normal period-end closing. SAP NetWeaver BI is required in order to use this function.[13] Use of the daily production cost function is described in the section titled "Daily Production Costs."

Production confirmation of the order is entered at the reporting points. The components of each order are determined by the planning runs of the component matrix and date and time that the confirmations are entered. After data is transferred to SAP ERP, GIs are posted to associated product cost collectors in inventory management software within SAP ERP. The activities that must be performed for an order are determined according to the components by the activity matrix. Once the data that is recorded in SAP APO has been transferred to SAP ERP, the activities are calculated in controlling software and posted as internal activity allocations in the product cost collector. Activities are only posted asynchronously.

An entry document is created for each confirmation in SAP APO. A backflush document is generated from the entry document in the production planning (PP) component. Withdrawals for a given material component and the activities for a given resource and product cost collector are aggregated and posted as withdrawals in each period in the inventory management software of SAP APO, as well as in the product cost collector, using the transaction *Parallel Processing of Backflushes (PPCGO)*.[14]

Variances can be entered directly in the confirmation. Planned quantities can be taken from the RPM, and users can enter the corresponding actual quantities. These quantities are later transferred to SAP ERP. There is also a separate function for entering variances in discrete industry manufacturing software that enables users to input variances for a product cost collector directly, without reference to a manufacturing order. This provides detailed variance valuation and analysis in controlling software.

When the product is completed and the final confirmation has been entered, the stock segment is debited with the value of the GR and the product cost collector is credited accordingly. Because no sales-order cost estimate was created due to the high production volume, the product is costed at the time of GR. This GR cost estimate uses the data from components in the backflush documents. The cost component split for each GR cost estimate is saved to the database.[15]

The cancellation of a confirmation with reference to a document is not possible; instead, the postings of negative quantities can be used for that purpose.

Postprocessing must be triggered for parts that had errors. Customer enhancements exist for error handling in combination with valuation to help, for example, perform a plausibility check of costing results or set a price for GRs.

At the end of the period, WIP and scrap variance are determined and reported in accordance with the individual product value. WIP is determined based on the quantities confirmed at the reporting points and is calculated using target quantities for components and activities that correspond to the confirmed assembly quantities. These quantities are valued during the WIP calculation process. The component and activity quantities are valued in accordance with the valuation variant specified in the planned costing variant of the corresponding product cost collector (WIP at target costs). The target quantities for components and activities are determined from the quantities specified in the product view of iPPE. WIP is only calculated if a results-analysis key has been entered in the affected product cost collector. This scenario supports parallel valuation and transfer prices in the calculation of WIP and scrap.

---

13. SAP NetWeaver BI includes queries. It is also possible to define your own queries.

14. SAP recommends running the report PPC1_CONF_GO as a scheduled background job to perform this step.

15. Saving the itemization is not recommended due to the high data volume.

In variance calculation, the variance categories are determined on the basis of the confirmation in SAP APO. Planned quantities are determined from the RPM. The corresponding actual quantities can be specified in SAP APO during the dialog-based confirmation. Planned and actual quantities are then transferred into SAP ERP. Separate recording of variances in SAP ERP enables variances to be assigned directly to a product cost collector without reference to a manufacturing order. This provides detailed variance information in controlling software, where the variances are valuated and analyzed with the variance-calculation function.

The daily production costs function enables companies to determine production costs for product cost collectors used in the confirmation in SAP APO, independently of the normal period-end closing process. For example, data can be analyzed for specific days, weeks, or months.

Variance Calculation for Product Cost Collectors with Quantity-Based Valuation

Variance calculation software enables you to determine the variances for product cost collectors with quantity-based valuation. This software is available only for product cost collectors manufactured on the basis of an iPPE quantity structure. Variance calculation software does the following:

- Shows the variance between target costs and control costs
- Calculates the difference between actual costs and WIP allocated to an object on the one hand, and the credit from goods-receipt postings (total variance) on the other
- Determines the scrap variances by valuating the unplanned scrap quantities at target cost
- Determines production variances
- Explains how the variances originated and assigns the variances to different variance categories depending on the cause
- Updates the variances for each object by cost element or cost element and origin

The knowledge acquired through variance calculation software allows you to determine an efficient way to control production costs. It is also possible to analyze the data for specific days, weeks, or months in SAP NetWeaver BI using the daily production costs function.

The schedule-manager function facilitates the period-end closing process. Together with the flow definition, it enables users to correct errors in objects using the multilevel work list. User-defined error management enables the indirect influence of the program flow of the variance calculation.

The product cost collector for which variances should be determined must have a valid variance key. When determining costs for variances, the *Scrap* indicator in the variance key is ignored. That is, scrap variances are always reported as long as scrap is activated in the valuation variant. In addition, the setting for *Write line items* is ignored – line items are never saved. You can use the indicator for *Material origin* to enable the software to determine which primary cost element caused the variances.

When actual costs are posted, target quantities for component withdrawals and activities are specified in accordance with the posted assembly quantities. When target costs are calculated, these components and activity quantities are valuated directly using the valuation variant specified in the *Costing variant planned* of the product cost collector. No existing cost estimate is used in the valuation. Consequently, the valuation variant for WIP and scrap plays no role in quantity-based valuation. Assignment of the target cost version affects the variance calculation. Furthermore, the scope of functions in target cost calculation varies depending on the production environment. The indicators *mixed-price variances* and *minor differences* are ignored in this scenario. WIP should always be calculated **before** variances.

The variance calculation function determines planned quantities from the RPM. The corresponding actual quantities can be specified in SAP APO during the confirmation. The planned and actual quantities are then transferred to SAP ERP. Separate recording of variances in SAP ERP enables variances to be assigned directly to a product cost collector without reference to a production order. This provides detailed variance information in controlling software, where the variances are valuated and analyzed with the variance calculation function.

The variance calculation function always compares control costs with target costs. SAP ERP calculates target and control costs in accordance with the type of variance calculation and the production approach. In this scenario, only periodic variance calculation is performed in which the target costs of the period are compared with the control costs of the period.

Daily Production Costs

The daily production costs function enables short-term cost controlling for the product cost collectors used in backflushes in SAP APO, independently of the normal period-end closing process. For example, costs can be analyzed on a daily, weekly, or monthly basis. This means that key figures such as target, plan, and actual values, as well as variances and scrap values, are available for short-term decision support.

This function also supports the reporting tool , allowing you to analyze results through queries in SAP NetWeaver BI. This function can be used only when a product cost collector such as the cost object for production backflush in SAP APO is used with quantity-based valuation.

Using the daily production costs function requires that data be extracted from discrete industry manufacturing software in SAP ERP and stored in SAP NetWeaver BI. Separate queries exist for the daily production costs function.[16] More information on queries can be found in the SAP help portal for SAP NetWeaver BI.

New queries are available for analyzing costs on a daily, weekly, or monthly basis. These analyses (such as target-to-actual comparisons) enable you to react quickly when there are variances in the quantities of components or activities consumed.

Because all key figures (actual costs, target costs, variances, scrap, and WIP) are made available after a simplified valuation process that differs from the valuation basis of the normal period-end closing process, the key figures of daily production costs cannot be compared with key figures in the standard reports.

The daily production costs function calculates the key figures as shown in Table 12. It calculates actual quantities of components and activities consumed at reporting points, variance quantities, WIP quantities, target quantities, and scrap quantities. Quantities are based on a similar valuation method using a simplified principle including actual costs, target costs, variances, actual scrap, and WIP.[17]

CALCULATION	DESCRIPTION
Variances	Variance quantities (actual quantities – target quantities) *X* Price based on simplified valuation
Approximation for actual costs	Actual quantity (quantity actually entered) *X* Price based on simplified valuation
Approximation for WIP	WIP quantities *X* Price based on simplified valuation (The change in WIP is calculated)
Scrap	Scrap quantity *X* Price based on simplified valuation
Target costs	Actual costs *X* Variances

Table 12: Calculation of the Key Figures

16. SAP NetWeaver BI includes queries. It is also possible to define your own queries.
17. The valuation variant used to valuate the quantities in daily production costs is the costing variant planned of the product cost collector. For performance reasons, this valuation variant should be the same as the valuation variant in goods receipt costing. This valuation variant is taken from the requirements class.

The following functions in SAP ERP are not supported in this scenario:

- Overhead rates on actual costs and revaluation at actual costs
- Price variances
- Template allocation

WIP

Unfinished products that have not yet been transferred into finished goods inventory can be valuated by calculating the WIP on the corresponding product cost collectors. If activities are to be included in backflushes and costing, a link in iPPE between the iPPE resource (or the mode) and overhead cost controlling software must be established first. A results analysis key must be assigned to the cost collector; the assignment cannot be changed once the WIP has been calculated for the first time.

WIP is valuated on a quantity basis. With every confirmation, the quantity of input components withdrawn and activities used that were not confirmed as scrap are recorded as WIP. This WIP is reduced by the quantities and activities used for the GR that was posted to the product cost collector. WIP is determined on the basis of the quantities confirmed at the reporting points and is calculated using the target quantities for components and activities corresponding to the confirmed assembly quantities. These quantities are valuated during the WIP calculation process. The component and activity quantities are valuated in accordance with the valuation variant specified in the planned costing variant of the corresponding product cost collector (WIP at target costs). The target quantities for components and activities are determined from the quantities specified in the product view of iPPE. WIP is only calculated if a results analysis key has been entered in the affected product cost collector. The WIP calculation process can be executed in the same way that it is performed by default in SAP ERP.

OUTLOOK AND EXTENSIONS

The scenario described in this paper has been developed and improved over several years. As a result, it represents a complete, mature concept that has gone through several improvements and enhancements. Therefore, only minor changes are expected for the related core solutions in the future. However, enhancement that targets manufacturing in small volumes has already been provided through the option to explode product structures step-by-step. In addition, there are options for expansion through integration with other SAP software and partner solutions, particularly for shop-floor control (SFC) in the MES area.

To put this scenario and the possible extensions into perspective, it is essential to understand the lean management approach, which is sometimes referred to as adaptive manufacturing. Lean manufacturing is a production philosophy based on the Toyota Production System (TPS) that seeks to increase throughput of quality products with fewer resources by matching production rates with prevalent demand, smoothing production rate consistently with demand, executing replenishments dependent on sales (finished goods) and usage (components), and eliminating or minimizing activities that are not value-adding. A lean enterprise is able to lower its manufacturing costs and inventories while delivering high-quality products with shorter lead times.

Lean manufacturing includes a set of principles that aim to keep demand at a consistent level with incremental, smooth adjustments; adopt simple visual production control methods that mirror the shop floor; and limit buffer and WIP inventories. Standardized and repeatable processes are adapted for all production, procurement, and supply chain processes. Lean manufacturing is represented by methods such as kanban, JIT, kaizen, and continuous replenishment. Order-dependent production with standardized tools, as discussed in this paper, is a type of lean-production process.

Lean manufacturing also requires the integration of all production systems within an enterprise and across the supply chain. Generally, a production system can be divided into three layers.

At the lowest level are shop-floor automation and control systems (SFACs) that collect data from the programmable logic controllers (PLCs) and sensors that are connected to the machinery on the factory or plant floor. SFACs collect data about what is happening at each machine and provide information about cycle times, operating efficiencies, machine breakdowns, downtime, quality indexes, and predictive-maintenance requirements. At the next level are MESs that track all customer orders, schedules, labor, resources, and inventory across the production line and provide information about material availability and consumption, capacity availability and utilization, schedule changes, product genealogy tracking, and quality management (QM). At the uppermost level are enterprise solutions for ERP and other areas such as SCM that plan and record transaction data to measure variance against set performance targets such as total cost of production and variance, labor and resource productivity, order fill rates and cycle times, and fixed and variable asset utilization.

Figures 34 and 35 provide an overview of the different layers according to the ANSI/ISA-95 standard that covers the integration of the different manufacturing layers in a company.

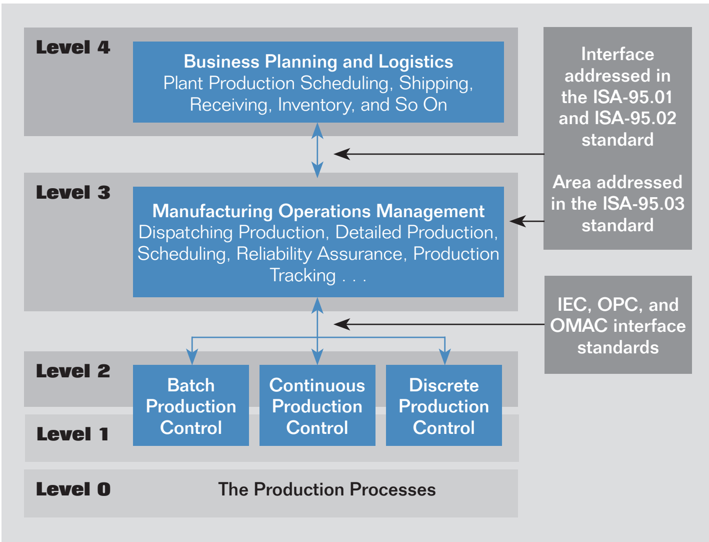

Figure 34: Functional Hierarchy of a Manufacturing Enterprise

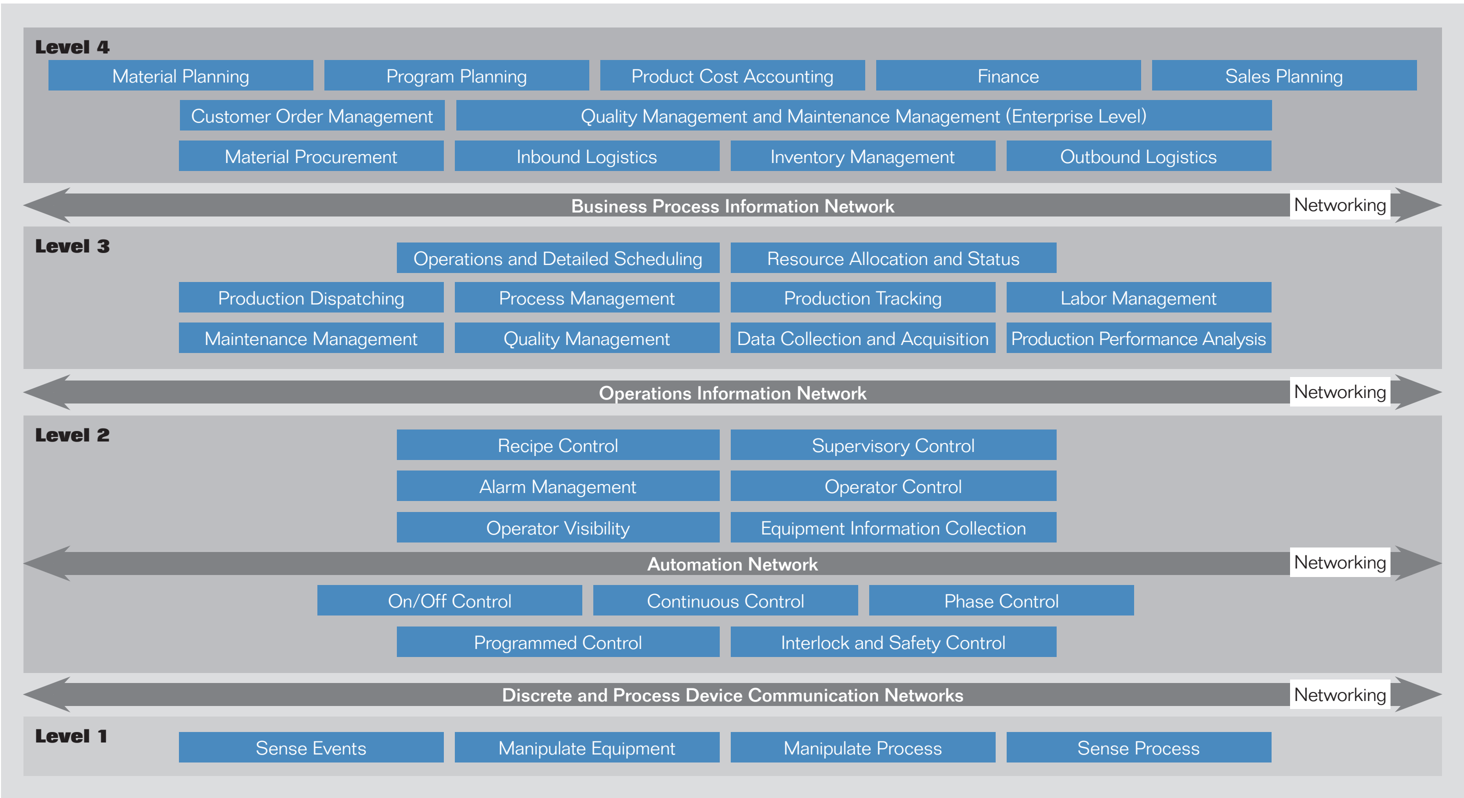

Figure 35: Manufacturing Processes (ANSI/ISA-95)

As shown in the figures, Level 4 can be assigned to the ERP area while Level 3 comprises the MES of the manufacturing environment. The SFAC is typically found in Levels 1 and 2. One objective of ANSI/ISA-95 is the standardization of interfaces between these levels.

Unfortunately, in most manufacturing companies today these layers are not integrated, especially from the factory (MES) to the enterprise (ERP) level. As a consequence, companies often employ large numbers of people to transfer redundant production batch data from their MES to their ERP systems. This is a wasteful and costly exercise that can also generate human error in the data-entry process. Most of all, the data is often out of date by the time it is entered into the ERP system, which inhibits business managers from getting a correct real-time picture of the production process and its possible problems.

While the SFAC and MES layers tend to be integrated at most companies, it is equally likely that the heterogeneity of this environment with homegrown, legacy, and point applications from multiple vendors and differing architecture platforms may also result in disruptions The business implication of the ability to compare actual manufacturing performance against set targets is not evident until MES data and exceptions from the factory floor arrive in the ERP system. When the ERP system is integrated seamlessly with the factory MES layer, you have a business context for manufacturing transactions, exceptions, and issues captured on the factory floor. On the other hand, a disconnect between manufacturing and enterprise business processes can lead to high costs, lost value, and missed performance targets.

To overcome these situations, companies must move from a reaction mindset to a planning mindset through an adaptive paradigm and the creation of lean supply networks. The key factor for this transformation is adaptive manufacturing. It enables timely collaboration with suppliers and manufacturing partners to solve potential upcoming problems; proactive detection of changes in demand and supply; depletion of capacity buffers against uncertainty; consistent delivery of customer orders at the lowest costs of inventory and fulfillment; and the ability to continuously monitor, analyze, and improve the supply chain, as well as production and procurement processes.

SAP offerings have evolved continuously to meet these requirements. Combining Web services standards where appropriate with its proven library of open application programming interfaces (APIs), SAP helps companies adopt an enterprise service-oriented architecture (enterprise SOA) that enables them to compose new applications and enable business processes rapidly using enterprise services. With this technology, application performance can be improved dramatically in terms of usability and scalability.

With the exception of production planning and detailed scheduling (PP/DS) software in SAP APO, SAP software for manufacturing is fundamentally ERP-centric and draws on software for ERP, SCM, and PLM that is integrated through the SAP NetWeaver platform. SAP NetWeaver also enables integration with existing homegrown, legacy, multivendor, and point applications, as well as composite applications and other third-party applications developed by partners. The integration of all of these disparate applications through the SAP NetWeaver Exchange Infrastructure (SAP NetWeaver XI) and SAP NetWeaver Portal components provides users with a manufacturing role-based view (dashboard) that lets them draw data from virtually any solution or application – SAP or non-SAP. This in turn helps manufacturers to optimally plan, schedule, sequence, execute, and monitor production on the shop floor; analyze performance; and adapt to unforeseen changes in demand or supply – in short, to drive lean manufacturing.

The SAP Manufacturing solution leverages SAP NetWeaver XI to provide an open standard, flexible, scalable, and industrial-strength platform for manufacturing that integrates enterprise applications for ERP, SCM, and PLM with human-machine interface (HMI) or supervisory control and data acquisition (SCADA) systems on the shop floor. It enables companies to drive intraplant, interplant, and supplier connectivity, allowing collaboration and business process management (BPM) between trading partners and facilitating dashboards with relevant key performance indicators (KPIs) and decision support. It provides a manufacturing integration platform (MIP) that leverages existing investments to lower TCO.

The manufacturing dashboard in SAP Manufacturing provides a configurable role-based entry page for production personnel. It delivers integrated planning and execution decision support, relevant manufacturing, and business content; real-time exception detection and management; and comprehensive analytics and reporting tools. It provides a real-time snapshot of factory or production-line operations at a glance, proactive response to exceptions, timely execution on production plans within budget, and access to relevant KPIs to continuously improve performance.

Adaptive manufacturing supports improved visibility, responsiveness, and performance. It enables companies to have near-real-time visibility to customer orders across multiple plants from schedule to dispatch, connecting MES, SAP Manufacturing, and third-party applications to SAP ERP through SAP NetWeaver XI. With adaptive manufacturing approaches, companies can proactively detect issues with machines, materials, labor, and product quality by checking real-time status through role-based views and alerts. You can evaluate actual production costs and variances against the budget and issue appropriate reports through SAP NetWeaver BI. You can balance manufacturing priorities against changing demand conditions and align them with individual business objectives, and trade off and adjust these priorities in response to changing demand and supply conditions. You can respond to exceptions rapidly and cost-effectively by triggering the appropriate workflow with minimum manual intervention before exceptions attract the customer's attention. You can improve and leverage customer satisfaction for new revenue opportunities with increased on-time shipments while minimizing inventory on the factory floor. You can increase manufacturing margins with the ability to focus on the most profitable opportunities and minimize opportunity costs. And you can reduce labor costs by eliminating manual, redundant, and inaccurate MES data entry into SAP ERP. In essence, adaptive manufacturing increases manufacturing visibility and customer responsiveness so that the factory becomes the response buffer.

In some cases, SAP offerings will be complemented by partner products, because some system landscapes use SAP software for their MES and some use a third-party MES. SAP provides a list of recommended partner products for specific OEM and supplier scenarios. Also, SAP will deliver an integration package that enables easy implementation and extension of the software through standard integration methods between SAP software and the recommended partner product. Standardization will be achieved through the delivery of new enterprise services that will allow the integration of several manufacturing solutions using several ISA standards.

SAP xMII enables companies to synchronize manufacturing operations. Manufacturing synchronization means the electronic linkage of enterprise business processes and master data with plant manufacturing processes to run from a "single version of the truth," thereby achieving manufacturing excellence.

With SAP xMII, manufacturing integration is enabled by a MIP that connects MES with ERP, leveraging current IT investments and functionalities and enabling interplant and intraplant visibility; proactive alerts for machine, material, labor, and quality exceptions; and visibility of actual production costs and variances.

Manufacturing intelligence is achieved by the use of role-specific, configurable dashboards for production personnel that enable them to meet or even exceed production goals. The dashboards offer a configurable entry page with decision support, alerts, event management, collaboration, and KPIs considering all relevant manufacturing and business contents.

SUMMARY

The approach explored in this paper has been honed and developed in collaboration with automotive companies over many years and represents a solution that is well suited to the requirements of today's automotive industry.

Variant Configuration

In the scenario discussed in this paper, the classification in SAP software is essential for the representation of variant structures. The classification system, with its classes and object dependencies, allows you to apply characteristics to configurable products. Configuration profiles and object dependencies enable customers to individually configure their vehicles. At the same time, you can avoid excessive complexity by enabling the creation of products that are only partly configurable. Selection conditions ensure that all objects relevant to a specific variant are selected and are mainly used in BOMs. Constraints enable the dynamic control of characteristics and their values and are important for the validation of sales orders.

Companies can use iPPE to connect different corporate divisions with each other through a uniform, shared database. This means the production area can cooperate and exchange data with both the sales and development areas on a consistent basis. The modeling in iPPE discussed here uses so-called super structures, such as super BOMs and super routings. A super BOM includes all possible components of a configurable product within one BOM structure; therefore, object dependencies are important in avoiding inconsistencies. A super routing includes a master sequence, and can also have additional parallel and alternative sequences divided into operations and suboperations. Object dependencies determine whether or not a routing activity is selected. However, in iPPE, the standard BOM and routing are replaced by the PVS, the process model, and factory layout with only the PVS possessing object dependencies. A great advantage of iPPE is the ability to drag and relate objects easily, together with a graphical representation of the object structures in the iPPE workbench and the ability to use advanced planning tools such as the RPM. iPPE is effective in modeling high volumes and many structural relationships in configurable products, when using collaboration and advanced scheduling functionality in SAP APO. However, iPPE is not compatible with basic standard ERP functions. If such functions are preferred, the standard variant configuration in the SAP ERP is more appropriate. Drag&Relate is also provided with SAP ERP, but in a less sophisticated form than that in iPPE.

With the PVS, companies can illustrate a complex variant structure with extensive object dependencies. This lets you represent all characteristic values of a product in a common, user-friendly structure greatly increasing the interactivity and the simplicity of variant configuration scenarios. The PVS provides a redundancy-free description of products or product families with many variants together with a consistent data basis for all enterprise areas that work with the variant structure. You can even connect to DMU viewers and CAD programs. Using this newly designed interface as well as the DMS optimizes information flow within the company. The PVS can be used to monitor a product with all of its variants through all phases of the life cycle consistently, beginning with the idea for a product. While nonconfigurable materials can be maintained in the PVS, it is especially suited for highly configurable materials.

Access nodes, view nodes, and the structure nodes that contain several material assignments dependent on object dependencies make possible the hierarchical and logical grouping of the product structure, enabling several selection options and possibilities. Assembly nodes can be used to group standard materials together.

Phantom assemblies make the logical grouping of materials possible. They represent assemblies that have their own product structure, but do not physically exist. The components of the phantom assembly are incorporated directly in the superordinate product. The product structure of the superordinate product contains a reference to the phantom assembly. A phantom assembly can be referenced more than once in the same product structure. Changes are visible and effective immediately at all usage locations.

Accesses (combinations of variants and alternatives) can be used to build complex hierarchical structures in the PVS. An access always consists of one variant and one alternative. The variant represents the manufactured material, while the alternative represents the way to build the material. Nodes on different levels in a hierarchical PVS are linked via the alternatives. Side-access functionality is available for displaying multilevel configurations (header and components of configurable materials) in one simulation explosion. This multiple configuration is called "nested families" because the second configuration is nested within the first configuration.

With the use of accesses and configuration possibilities at several levels, data can be used for other projects, such as the production of components. In addition, conventional BOMs can be transformed into a PVS, and vice versa, which adds to the flexibility of this approach.

Focus objects allow modification to the general PVS model without the need to change the original model; the changes can only be seen in the focus context. Several references to the original structures are possible. For example, reference objects appear in the focus structure but they can only be changed in the original structure, whereas copied objects without reference to the original structure can be changed. Focus structures are used for grouping specific structures of a master PVS for development changes, deletions, or structure additions. The focus is intended to provide a product development environment that is distinct from the master product model.

The routing data of a configurable product is maintained in the process structure, which consists of several activity and grouping nodes to illustrate highly complex routings. The use of grouping nodes allows the buildup of multilevel process hierarchies. Activities that are the basis of the process model describe certain activities or work content. The grouping of several activities enables companies to carry out related activities simultaneously when a certain component is selected. Modes describe how the activities are executed and can have several resources assigned. In addition to HR, PRTs and planning resources are also available. Mode resources can be used for activity cost calculation or the activity backflush in the RPM, among other things. In SAP software, either HR or machine resources are used to perform operations. Resources are related to the factory layout through a line balance. Capacity constraints of resources are not considered in planning runs, but the load at mode resources can act as an input to determine takt time and other input. Takt time is the actual basis for vehicle scheduling.

FLOs are used to model the factory or production plant. Line design enables the flexible structuring of production environments, including the combination of networks and hierarchies. Besides the necessary line header, several substructures are possible; a line can be divided into further stations and work packages (jobs). The resources at different line stations are the basis for scheduling activities, with line balance information in the header node. The ability to assign supply areas to line segments enables you to establish pull-oriented replenishment systems such as kanban. Action points at lines can be used to perform backflush activities and tracking and tracing.

The process structures and line structure share the same interactive, user-friendly, single point of access. Because they also use the iPPE workbench, orientation is simplified with the ability to manage all structures under a uniform interface. You can construct a parallel network of routes and specify the available resources at the same time.

The scenario discussed in this paper uses takt scheduling instead of lead-time scheduling. Takt scheduling equals the fixed takt time multiplied by the number of takts. Using this technique, you can perform simple scheduling of high volumes in a short period of time. Since the rate is dependent on the line resource, the number of takts does not influence output – only the WIP changes, with no impact on stock levels. The takt rate is defined in the line resource, so the focus of takt scheduling is on ACT and routings. Lead-time scheduling, by contrast, cumulates labor and machine requirements to determine the total working time. Unproductive time intervals (like waiting or transport times) are not considered in lead-time scheduling. Thus, errors can be encountered. In takt scheduling, unproductive time intervals are defined.

One of the key benefits of using iPPE is the ability to relate all the previously mentioned applications. You can relate the PVS to ACT by linking materials to activities; you can handle material assignment via the structure nodes or their variants. You can relate the activity structure to FLO by linking activities to plant locations via the activity modes. With this degree of integration of master data, you can determine exactly when and where a component is required.

Line balance functionality is used to link ACT and FLO. Mode resources are related to line objects through the context of a line balance. Assigning operations to a station or jobs achieves an optimal work load of the station or jobs. To determine if a line is properly balanced, you can create a model and assign it to the line balance. The model mix represents the relative percentage of different vehicle models and can be assigned to the line balance as a basis for line balancing. However, it is not mandatory to create a model mix, because SAP APO can do this automatically. If the average weighted takt is equal to or smaller than the takt time, the line is balanced. The process of using multiple specific model mixes to determine if the activity assignment matches the given takt time is called line balancing.

ECM software is a central, integral part of PDM functionality in SAP ERP, and it ensures that there is a complete history of any changes made to product data. ECM software can be used to edit PVS variants and modes. SAP ERP is therefore able to make operational use of different change statuses. ECM software enables the monitoring and seamless documentation of changes according to notification settings, as well as planning and conversion for defined effectivities.

Production Planning

The iPPE is integrated not only in SAP ERP, but also in the SAP SCM application and SAP APO, so the transfer of structural data is possible via the CIF without any significant problems. This presupposes that integration models have been carefully maintained – otherwise, there is a danger of inconsistent data. Because SAP APO can create planning data from iPPE data, the transformation of relevant data is also possible without the risk of severe problems.

Before sending iPPE data from SAP ERP to SAP APO, a production version must be created in SAP ERP. The production version tells the system which BOM (or PVS), routing (ACT), and line (FLO) to use when the product is manufactured. In addition, a product cost collector must be created for each vehicle that you plan to produce. During production, all costs (material, labor, and overhead) are collected against this order. At period closing, these costs are settled to the appropriate financial accounts. The interface alone, however, is not sufficient to start data transfer between SAP ERP and SAP APO. In order to send data, you must first create an integration model. When you generate an integration model, the data objects to be selected from the total dataset in SAP ERP for transfer to SAP APO are specified. Any number of versions of an integration model can be created, but only one version can be active at a time. The structure of an integration model influences system performance; the greater the number of integration models per object type, the longer the runtime for determination of target systems. As long as an integration model is active, both systems will continue to communicate data.

The objective of an efficient production system is the generation of a feasible and optimal plan for the manufacture of configurable products in high volumes – a plan that considers balanced usage of production resources, early identification of potential bottlenecks, and reliable delivery dates that lead to increased customer satisfaction. Also, line capacity must be utilized efficiently. To achieve all of these requirements, MMP and interactive sequencing software can be used in SAP APO.

The aim of MMP is to create a production schedule in the medium- to long-term planning horizon. Various heuristic procedures are available for dispatching the orders. The software can use various algorithms to determine the optimal allocation of orders to buckets. Complete line networks, as well as individual lines, can be planned, and multiline planning with alternative lines is also possible. In MMP, all demands are typically scheduled in daily buckets.

In the short-term planning period, the software uses period packages to calculate an order sequence with exact start and end times, which takes place in sequencing software. This order sequence takes restrictions and customer-required dates into account and fulfills certain business goals that may include an equal load of line segments or takts, a minimization of restriction violations, or a minimization of the absolute schedule deviation. Interactive sequencing software enables the easy manual change of the production sequences; planning results can be processed manually in short-time horizons and orders can be displayed and changed.

To execute planning activities, the system uses SAP liveCache technology. To improve system performance, data is stored in RAM instead of a data base. By eliminating the need to retrieve information from the database, the system can perform planning functions much more rapidly. These functions can include calculation of confirmation dates, model mix calculation of daily buckets, sequencing, or high-volume BOM/PVS explosion in demand planning. SAP liveCache is a database engine that helps guarantee the best possible performance. Based on SAP database technology, it is used for managing complex objects in SAP applications such as SAP SCM (including SAP APO) and SAP PLM. In applications of this type, large volumes of data must be permanently available and modifiable.

Several restriction types can be used multiple times in SAP APO; the software uses weightings to determine the relevant restriction. All restrictions use object dependencies and can be assigned to multiple line objects. Possible restrictions include quantity, spacing, and distribution requirements. Several mathematical algorithms can be used to solve the MMP run, such as the genetic algorithm, linear programming, or percentage smoothing. It is also possible to define one's own solving algorithms. In addition, the planning run includes the restrictions that exist for certain line objects – for example, if a vehicle can only move on specific paths through the plant. Whereas MMP software considers the entire line net, interactive sequencing software only plans against the planning segment. The orders assigned to a particular bucket are arranged in a specific sequence; bucket size can relate to a shift or a day. Because the model mix approach uses aggregated spacing restrictions, it should be possible to obtain a feasible sequence for the bucket orders.

Given the large order variability of individually configured customer orders, the large volume of data, the complex structures, the frequency of engineering and customer changes, and problems with supply, it is important to be able to respond quickly and flexibly. The fast explosion of the PVS is an essential piece in this process. Besides performing high-frequency planning and replanning, as well as fast MRP, companies must also be able to use precise and current data and fast reporting tools and business functions. This is key to being able to react quickly to order changes, respond to engineering changes, and flexibly and collaboratively respond to changes caused by issues on the supply side. Companies can meet these requirements by using the RPM, a product-related database that is stored in SAP liveCache for SAP APO. Two RPM matrices are available for planning: the component variant matrix for calculating the required components, and the activity matrix for calculating the required activities.

Planning in the RPM is based on the iPPE data in SAP APO. Any changes made to master data – for example, to the PVS or the line resource – or changes in the order sequence are automatically transferred to the RPM. While the scenario in this paper uses the RPM, the appropriate method depends on the planning situation and its prerequisites. Depending upon the need for various factors such as rapid planning, highly configurable products, or integration back to standard SAP ERP software, a combination of these planning options may be chosen. The RPM is generally better suited for configurable products with a high order and production volume, a standard product group, and manageable engineering content, such as vehicles and components in the automotive industry. The strengths of the RPM are in high-volume backflush and subdaily planning. The size of the matrices in SAP liveCache is almost exclusively determined by the amount of lines representing components or activities, so the RPM is most impressive when dealing with a high volume of orders representing the columns of the matrices. On the other hand, if the component list becomes too complex – particularly for product structures with a high share of ETO or CTO components – the RPM is not as efficient as other planning methods. It is even less effective for relatively small production volumes. The same issues apply to hierarchical product structures, such as situations where several phantom assemblies exist. Because the RPM first explodes the maximum structure of products or activities and then calculates the requirements, it also explodes nodes that might not be exploded by a top-down explosion. If several alternatives exist at a level, the top-down explosion can exclude nodes from the explosion based on the choices made, thereby reducing the system load.

The rows of a planning matrix contain all the components of a product, which the software determines from the component variants in the PVS. Or it contains all the activities, which the system determines by exploding the process structure. The columns contain the orders that are lined up and planned orders for the production by SAP APO. The use of a component or an activity in an order is indicated by an x in the appropriate row of the planning matrix. Reading the component matrix vertically determines the components per order, the BOM, and the component requirements. Writing to the matrix allows MRP, backflush, and impulse activities, as well as sequencing activities and the generation of sequenced JIT calls. Reading the matrix horizontally determines the total component requirements.

The activity matrix enables the calculation of actual resource requirements per work station and aggregates all activities that are carried out at a station. Actual working hours can be matched with the working hours available. Several additional activities are integrated into the matrix, including backflushing (posting of all performed activities and capacity reduction), controlling (valuation of all activities per vehicle and resource capacity), and MMP (material matching of necessary activities against resources).

Production Execution and Control

The ability to execute actual production is critically important, and it is essential to be able to completely control the production process at any time. Companies need to be able to track production activities and to stop or change processes. And you need the ability to perform several backflush processes together with cost settlements and other postings. The action handler is a component of SAP APO that is used for the automatic or manual execution of functions before and during production. It can link planning software in SAP APO with an external system that is responsible for controlling production.

There are two types of action handlers: an automated action handler that repeats the same actions several times and is used for recurrent production steps; and an easy-to-use manual action handler that comes into play whenever production processing steps for single orders need to be carried out. SAP APO provides several standard actions that can be changed according to a company's specific needs. It is also possible to define or program one's own actions.

To control the production process, the action handler uses action points. These are points in a production line or a work center at which an event can cause the automatic trigger of an action in SAP APO. There are different types of action points, including obligatory and optional ones, which handle the execution of actions differently. The action points of the automated action handler can be the same as the ones in iPPE, so it is possible to use them as reporting points for backflushing. SAP APO automatically copies all action points that are created in iPPE to the master data of the action handler, including predecessor and successor relationships. The software also automatically determines the resource for the action point using the element of the line structure to which the action point is assigned. This enables you to use action points as reporting points for backflush activities, reducing goods movements load.

An action point can be assigned several actions, so for each coupling it is possible to define a responsible person. The sequence of actions is not predetermined, and you can run each action independently of the others. The same action can have different parameters at several action points.

The display of production tracking information within the planned order management area allows users to check the production progress of selected planned orders and follow up on errors in the production process. While enabling users to create tracking reports, business add-ons can be used to save tracking data that includes additional customer-specific data.

When a vehicle is planned on one line but manufactured on another – a move called a line change – the change is automatically recognized when the vehicle passes the corresponding reporting point or tracking point. The components and activities of the matrices are automatically adjusted according to the change in the production version, including changes to the RPM and a new explosion of the product structure together with the correction of requirements.

You can use the backflush component in an environment where there is a large volume of orders with small order quantities – often only one piece flow, as described in this scenario. Backflush can be carried out very quickly. This is due both to a new link to SAP APO – where the creation of the backflush is separated from the processing of backflush data – and to the increased separation of logistics and controlling functions. Backflush is created in SAP APO. Subsequent processes, such as the posting of goods movements and production activities, are carried out separately in SAP ERP. To speed up processing in SAP ERP, synchronous and asynchronous goods movements are posted separately. Through a backflush profile in SAP APO, users have flexible access to the backflush transaction as well as the ability to trigger backflush via the action handler.

Backflushing in SAP APO is always carried out for a specific reporting point. Each order always refers to exactly one reporting point structure; reporting point structures can be changed during production. The definition of reporting points is possible in line design at the beginning and (or) end of a line segment.

Production backflushes, which are sent from SAP APO to SAP ERP, contain components and activities to be posted. Components can be posted either synchronously or asynchronously, whereas activities are always posted asynchronously.

In a backflush process for a high-volume production, the number of cost collectors increases significantly, which can lead to a deterioration in performance. This occurs because material documents must be created for each cost collector even if the components are the same. To avoid this deterioration in performance, backflush can be executed in two steps. In a two-step production backflush, the requirements are adjusted in SAP APO after the first step. This method offers an advantage because logistical data is already updated before the data is posted in FI and CO software. Therefore, logistical data remains consistent. Goods movements are aggregated before they are posted, thereby improving system performance. However, two-step backflush only makes sense in a system environment that provides enough idle time to post all the FI and CO data.

Finally, you can perform a profitability analysis using several resources. For a cost accounting profitability analysis, data must be transferred from the SD area twice – when the sales order is changed and during billing. A product cost collector should have been created for each vehicle variant. All production activities for this variant are posted against the corresponding cost collector. Based on settlement rules, the costs can then be allocated to other financial accounts. The cost collector is generic at the material level. That means that all vehicle costs for the same material are captured in the same cost collector. Therefore, vehicle costs can only be analyzed on a periodic basis and not for an individual vehicle.

Production cost controlling software in SAP APO enables the determination of stock values at the time of GR on the basis of the confirmed quantities for components and activities and the recording of progress in the software. Companies can determine WIP and scrap, for sales-order-specific costs on the basis of stock values, and can also calculate variances. The daily production cost function enables the determination of the short-term production cost for the product cost collectors used for confirmation in SAP APO independently of the normal period-end close. This process requires SAP NetWeaver BI.

Variance calculation enables the determination of variances for product cost collectors with quantity-based valuation. This functionality is available only for product cost collectors manufactured on the basis of an iPPE quantity structure. With this functionality, users can compare target costs and control costs and determine production and scrap variances, including their origin.

In closing, the scenario and solution discussed in this paper were specifically developed for a complex manufacturing environment with many variants and high-volume production that must remain fast and flexible. However, all of the software mentioned can be easily adapted to match another environment, such as a stock-oriented production environment or a production environment with high levels of engineering content. The software that SAP offers is highly configurable, enabling companies to model nearly all possible environments.

For more information about SAP software for the automotive industry, please contact your SAP representative or visit www.sap.com/industries/automotive/index.epx.

LIST OF ABBREVIATIONS

ACT	Process structure
API	Application programming interface
ATP	Available to promise
BOM	Bill of material
BPM	Business process management
CAD	Computer-aided design
CIF	Core interface that allows data exchange between the SAP® ERP application and the SAP Advanced Planning & Optimization component
CHAR	Character
CMP	Component applications
CO	Controlling
CRM	Customer relationship management
CTO	Configure to order
DATE	Effectivity parameters time interval
DIMP	SAP software for discrete industries
DMS	Document management system
DMU	Digital mock-up
ECM	Engineering change management
ECN	Engineering change number
ECO	Engineering change order
ECR	Engineering change request
Enterprise SOA	Enterprise service-oriented architecture
ERP	Enterprise resource planning
ETO	Engineer to order
FI	Financials
FIFO	First in, first out
FLO	Factory layout object
GI	Goods issue
GR	Goods receipt
HMI	Human-machine interface
iPPE	Integrated product and process engineering
JIT	Just-in-time
KPI	Key performance indicator
MATNR	Material number
MES	Manufacturing execution system
MIP	Manufacturing integration platform
MM/IM	Inventory management
MMP	Model mix planning
MRP	Material requirements planning
MTO	Make to order
MTS	Make to stock
PCS	Production control system
PDM	Product data management
PDS	Production data structure
PLC	Programmable logic controller
PLM	Product life-cycle management
PP	Production planning
PP/DS	Production planning and detailed scheduling
PPCGO	Parallel processing of backflushes
PRT	Production resource tool
PVS	Product variant structure
QM	Quality management
REM	Repetitive manufacturing
RFC	Remote function call
RPM	Rapid planning matrix
SAP APO	SAP Advanced Planning & Optimization component
SAP NetWeaver® BI	SAP NetWeaver Business Intelligence component
SAP NetWeaver XI	SAP NetWeaver Exchange Infrastructure component
SAP PLM	SAP Product Lifecycle Management application
SAP SCM	SAP Supply Chain Management application
SAP xMII	SAP xApp™ Manufacturing Integration and Intelligence composite application
SCADA	Supervisory control and data acquisition
SCM	Supply chain management
SD	Sales and distribution
SERNR	Serial number
SFC	Shop-floor control
SFAC	Shop-floor automation and control system
S2L	Supply to line
TCO	Total cost of ownership
TPS	Toyota Production System
WBS	Work breakdown structure
WIP	Work in progress

www.sap.com/contactsap

50 084 167 (07/04)