Model Mix Planning and Assembly Sequencing
with
SAP – APO Automotive Module

Master Thesis
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Acknowledgment

"THE LORD is my Shepherd [to feed, guide, and shield me], I shall not lack."

Psalm 23:1. (Amp.)

First of all I want to thank God for His provision and constant help in the works of my hands. I want to thank Dr. Klaus Solberg Søilen for his advice, constant help and encouragement throughout the work.

I want to thank my wife Martha Zewdie and my daughter Ruth Berhanu for their constant support whenever help is required.
Abstract

Effectively applying model mix and assembly sequencing can result in smooth part usage and balanced workloads on the automotive assembly line. I have studied the problem of production planning in automotive industry in terms of scheduling various models on an assembly line using SAP APO over a time horizon. The trends in automotive industry are moving from built to stock to built to order since more customers are demanding cars specific to their requirements. This shift of interest creates a big challenge on the whole supply chain and specifically on the shop floor in automotive industry. As the number of car variants increase, the amount of products to be ordered and cars to be made specific to customer requirements creates an additional challenge on the shop floor regarding resources (Labour, Material and Equipment) optimization. The resources optimization can be done by implementing a model mix and assembly sequencing concept based on the integrated Product and Process Engineering (iPPE) structure. Using iPPE structure and takt based scheduling in SAP APO give consistent results and make the planning process simpler as the number of car variants increases though the absence of model mix percentage calculating module and lack of flexibility in editing the iPPE structure are some of the weaknesses of the system. Sequencing between departments in automotive industry using SAP APO can be investigated further.
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Line balancing by hand becomes unwieldy as the problems grow in size, like in the automotive industry. Fortunately, there are software packages that will balance large lines quickly. Now in this case study we are using SAP APO to balance the lines. 71

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Statutory declaration

Hereby, I testify that I have done this master thesis only by using the stated references. I have declared the sources from which words, statements, figures and concepts are taken.

Bracknell, 10/07/2011

Place, Date

Tibebu Berhanu

Name, signature
Executive Summary

Automotive industries are all affected by the issues troubling their industry these days, from globalization and economic uncertainty to new technologies and increasing consumer demands, they are facing major challenges that often stand in the way of profitability and higher shareholder value.

In response, automakers around the world are trying their best to cut costs while focusing on improved product quality and design. Moving quickly and nimbly is imperative, yet the web of complexity in the industry, with its vast networks of suppliers and distribution channels, as well as a long history of bureaucracy, make it difficult for automakers to turn on a dime. They also recognize the need to build stronger strategic relationships with suppliers, dealers, and even competitors to get to market more quickly with the right product for consumers at the right price.

The complexities of globalization are compounded by the need to serve a more demanding customer base. Automotive consumers are intensifying their requirements. Increasingly, they are demanding products that fit their personalized specifications. Automakers are feeling pressure because there are more consumers demanding personalized goods. Traditional automotive industry characteristics will not meet increasing customer demands for a personalized experience. Typical automotive characteristics include: mass marketing, long delivery time, huge inventories, minimal customer contact, consumer compromises, and poor delivery reliability. The new, developing automotive world will be defined by rapid delivery time, increased quality, and customer-centric relationships. As with many industries, the auto industry is increasingly driven by the need to improve and maintain customer satisfaction.

The complexity doesn’t stop on organizing and getting the relationships sorted out in a well designed fashion but continues to shop floor, where the real value adding takes place. In this thesis we will address the shop floor problems, which are caused by the ever increasing demand to specific products from customers all over the world.

Therefore to produce different product variants on a given factory layout by using efficiently the resources we have to balance the lines. The specific demand fluctuation and the specific requirements of the automotive industry (e.g. several assembly plants, model mix constraints) should be dealt consistently to fulfil the demand on the time.
Therefore, mixed model assembly line sequencing should be done with respect to given due dates of orders. Model-Mix Planning enables the production of different models, types, and configurations on one or more production lines and arranges them efficiently based on bucket-oriented approach. Vehicle sequencing calculates an optimised vehicle sequence within a day. This helps us to calculate detailed sequences of cars for a single assembly line. In this thesis I have addressed this problem using SAP APO Automotive Module Planning Software.

The SAP APO software uses Integrated Product and Process Engineering (iPPE) structure, which will allow any automotive manufacturer to optimize the resources with in a very short time as the iPPE is an intelligently designed form of creating and processing master data for design, construction and production. The iPPE structure collects all the data for an entire product life cycle in one integrated model. It is particularly suited to products with many variants, like the automotive industry. One can use iPPE to document data, and later reuse and update it, from early phases of the product’s research and development process. You can represent a complete production model because iPPE allows you to keep the master data for Bill of Materials (BOMs), routings, and line design in one model. The absence of model mix percentage calculating module and lack of flexibility in editing the iPPE structure are some of the weaknesses of the SAP APO system.
Introduction

The present make trends in automotive industry shows, the customer request for a specific product, the need for short time delivery, high product quality are increasing tremendously. The increase in demand of specific car variants and the amount of additional parts according to customer’s demand is creating a big problem to be solved on the shop floor. To satisfy the ever-growing need of customers using the available/innovative technological means is inevitable to stay competent in the market. These demands of customers are also giving a great push for car manufacturers to change their production strategy. In this thesis we will try to answer the following problems, which are created by the aforementioned customer demands.

1. How do you optimize resources (Labour, Material and Equipment) on the shop floor in the ever demanding Automotive Industry with short lead time, high quality and many product variants? And which type of scheduling is most suited for the automotive industry?
2. How do you optimize assembly lines in automotive industry as the number of car variants increases dramatically?
3. How do you implement Model Mix Planning and Assembly Sequencing using SAP APO Automotive Module?
4. What are the weaknesses and strengths of SAP APO Automotive module as a production planning tool in automotive industry?

In this thesis these problems are addressed by theoretical methods and by using a sample production line. I have used 20 assembly stations with 2 hours takt time and five product variants.

As the number of car variants increase the resources on the shop floor to be allocated accordingly with out incurring unnecessary waste. This goal is achieved by the establishment of so-called model mix assembly lines into which flexible tools and automated assembly technology is integrated so that products may be manufactured in an almost arbitrary order. This model mix planning can be done in mid point scheduling and takt based scheduling. After going through both scheduling systems, I recommend rate dependant takt based scheduling as it gives a more consistent assembly line and resource allocation for the current assembly trend in the automotive industry.

Assembly sequencing can be achieved by assigning a manufacturing slot to each unit or vehicle. The schedule for each unit is established by applying the line speed and build rate to
the sequence. The schedule specifies when each unit is expected to enter (the line on) and leave (the line off) the line.

In APO automotive module the implementation of model mix planning and assembly sequencing is done using a built in iPPE (integrated product and process engineering) structure. Since this structure is the master mind of the planning and sequencing job the accuracy of the results depends on the accuracy of the information stored in the iPPE structure.

After implementing model mix planning and assembly sequencing in APO automotive module using the sample production data, I have found the following strengths and weaknesses of the system.

The product mix analysis is not included in the SAP APO Repetitive Manufacturing Module. Hence, one must calculate the product mix percentage before he/she began to solve the production planning process using SAP APO. The system doesn’t calculate the model mix percentage even though the sales data and other business aims are already within the system. The model mix percentage should be determined by separate software (usually excel sheet) developed by the specific company by taking the sales and other important data into consideration. In addition to the above weakness, attached resources or products to the model can not be edited easily.

We can plan large number of variants and resources within few minutes according to specific customer demand. Resources within complex shop organizations can be planned instantly for large number of orders and planning can be updated from time to time as the need arises. (from shift to shift, hours to hours….)

In general as it is tried to see the strong and the weak points of the automotive module, I recommend the SAP APO repetitive manufacturing module will be profitable if it is implemented in automotive industries. Currently there is no other standard software at the scale of SAP APO Automotive module. I suggest the following topics for future researches.

1. How to create sequencing between departments in automotive industry?
2. How to include pull system in APO automotive module?
3. What is the economy of scale of Lean manufacturing?
4. How to handle unknown situations in the most efficient way in lean manufacturing environments? Example: Natural disaster, Fire, war, unexpected fluctuation in stock markets, etc.
1. Problem statement and methodology

The major challenge in the configuration of automotive industry is to cope with the huge portfolio of customer specific product options while at the same time maintaining an efficient flow of products through the production system and utilizing common manufacturing equipment.

The large number of orders, the increasing number of product variants, demand fluctuations, variation of production rate and increase in accuracy of due date create big problem to be solved on the shop floor. Example: The BMW Group, for example, spent 55 million on its new European online-ordering system to cut order to delivery times by 20 days on the average. At the same time, BMW offers up to $10^{32}$ variants (at least theoretically), several thousands of them actually being demanded. Other manufacturers also declared their intention to decrease order to delivery times from an average of 40 days to about 15 days and try to make the transition from build to stock to build to order that has successfully been demonstrated by the computer industry, and first and foremost by its paragon Dell.

Therefore to deal with these increasing customer requirements we have to produce different product variants on a given factory layout by using efficiently the resources we have (by balancing the lines). The specific demand fluctuation and the specific requirements of the automotive industry (e.g. several assembly plants, model mix constraints) should be dealt consistently to fulfil the demand on the time. Therefore, mixed model assembly line sequencing should be done with respect to given due dates of orders. Model-Mix Planning enables the production of different models, types, and configurations on one or more production lines and arranges them efficiently based on bucket-oriented approach. Vehicle sequencing calculates an optimised vehicle sequence within a day. This helps us to calculate detailed sequences of cars for a single assembly line. In this thesis we will address this problem using SAP APO planning software with a case study. To address the aforementioned problems we have to start by answering the questions that are related to the automotive industry, so that we can have a comprehensive view of the whole automotive supply chain management.

1. What are the trends in Automotive Industry regarding supply chain and production?
2. Why are Car makers shifting from Built to Stock to Customized cars (Built to Order)?
3. What are the challenges of Built to order processes on the whole Supply Chain process?
4. How do you optimize resources (Labour, Material and Equipment) on the shop floor in the ever demanding Automotive Industry with short lead time, high quality and many product variants?

5. How do you optimize assembly lines in automotive industry as the number of car variants increases dramatically?

6. How do you implement Model Mix Planning and Assembly Sequencing using SAP APO Automotive Module?

7. What are the weaknesses and strengths of SAP APO Automotive module as a production planning tool in automotive industry?

The first section of the thesis (Chapter 2, 3 and 4) focuses on answering the first three questions by explaining trends in automotive industry, the introduction of supply chain management and the automotive supply chain management. In the supply chain management part the approaches to different structural Logistic processes and how the process looks like and the task distribution among each sections along the process chain is well discussed. Built to order, built to stock and their respective processes chain is well described by using diagrams. In the automotive supply chain part the supply chain is seen from two, structural and functional, perspectives. Functional attribute discusses on sales type, distribution type, production type and procurement type of a supply chain, which have to be specified for each member of the supply chain separately. In the functional attributes of the production system in a car assembly we will find the main aim of this thesis, which is the Model mix planning and assembly sequencing. Structural attribute describes the relations between different, legally separate members of a supply chain.

The second part of the thesis (Chapter 5) deals with the theoretical background of production planning task to enable us to see the whole automotive supply and planning operations. To work various planning tasks of automotive supply chains quite a lot of planning units must be involved. These planning tasks and the respective decisions can be assigned to several planning levels comprising different planning horizons (e.g. long, mid and short-term). To increase the reliability of the plan the importance of the duration of planning horizon is discussed here.

In the third parts of the thesis (chapter six) we will see the theoretical framework, which will enable us to answer the questions how to optimize resources and assembly lines (question 4, 5 and 6). The iPPE is a special modelling module for automotive industry comprising the
product variant structure, process structure and factory layout in a single structure. The access object will connect the product variant structure, process structure and factory layout. This makes planning very simple, even though the modelling part seems complicated. The line balancing, which paves a way for the run of the planning functions, is also discussed at the end of this section.

In the fourth section of the thesis (chapter 7) we will address the problems created on the shop floor by so many variants and optional parts by using a model mix planning method and following the procedures to determine the product mix percentages. The steps and their respective calculations used by SAP APO to determine the model mix planning results are discussed in detail. In this section we will address the problems how to optimize resources, how to optimize assembly lines and how to implement model mix planning.

The fifth section (chapter 8 and 9) of the thesis will address the assembly sequencing problem and the strengths and weaknesses of the SAP APO automotive module. A number of cars are to be produced are not identical, because different options are available as variants on the basic model. Cars in production are placed on an assembly line moving through various units that install options such as air conditioning and radios. The assembly line can thus be viewed as composed of slots and each car must be allocated to a single slot. The assembly line has different stations, which install the various options (air-conditioning, sun-roof, etc.). These stations have been designed to handle at most a certain percentage of the cars passing along the assembly line. In this section five different car variants at 2 hours takt time with 20 assembly stations are used to test model mix planning and assembly sequencing module.
2. Trends in automotive industry

The automotive industry involves multiple players in long, complex, global supply chains. The relationships within and between automotive supply chains in the past tended to be fixed, linear and clearly demarcated. Enormous potential, therefore, exists in creating an environment in which relationships between these players can be more direct, cost efficient and interactive. Supply chain management encompasses a wide set of interdependent, cross-industry business strategies that can reduce costs, expand revenue and increase market share through improved efficiency and effectiveness of the supply chain. The increased value is realised by collaboratively balancing all resources, and optimising the flow of goods, services and information from source to end customer.

Supply chain integration is now regarded as an indispensable element for success in manufacturing, and it is believed that supply chain superiority will provide a decisive competitive advantage. And as integration increases, joint resource dedication will follow. In the new information-based economy, firms compete on the basis of supply chain competitiveness rather than as individual entities. Industrial supply chains that are able to minimise frictions between the participants will gain competitiveness through price reduction and speed of response. The ideal being the creation of a dynamic and flexible network of Customer/supplier relationships and information flows that is activated by customer demand and can respond rapidly and reliably to consumers’ preferences.¹

The impetus for supply chain integration is driven by the new information and communication technologies (ICTs) based on microelectronics, telecommunications, computers and network-oriented software, which have provided the infrastructure for the new global Information Economy to operate. Network-oriented ICTs through the compression of space, time and knowledge allow for unprecedented speed and complexity in the management of the automotive supply chain. Electronic networks comprise the technological architecture of the new global economy. Information technology (IT) convergence between back office (i.e.

¹ Andrea Bardi A1 and Nicolo Guidotti Magnani Pascale, 2011, Pages: 67 – 90
J Econ Geogr, 2011, Pages: 559-586
Sagren Moodley, 2001, Pages: 1-3
finance and administration; operations planning and execution; purchasing; product development; research and development; human resources; and inventory/asset management) and front office (i.e. sales, marketing and customer service applications) systems to produce an integrated supply chain that can respond rapidly to changes in customer demand is now a reality, thus making it possible for all of a firm’s IT to be tightly integrated and architected for the Internet.

Supply chain management is concerned with how information can be used to change how and when products are moved in the value chain to increase efficiency. It is important to note, though, that supply chain management (SCM) has roots which precede e business. We use the term information technology (IT) to refer to computers, software, telecoms and the Internet. It is expected that the Internet will have a fundamental impact on how business is conducted, on firm behaviour and on industry structure. It is argued that e business technologies are a critical source of value creation in the Information Economy, and thus provides the firm with a distinctive competency in the marketplace. E-corporations have the potential to redefine traditional value chains and develop complex knowledge-sharing systems that connect pricing, product and design information with suppliers and customers. Theoretically, e business holds great potential for revamping traditional supply chains to improve data flow and streamline operations. An e-corporation recognises the power of strategic partnerships with its business constituencies. The alliances foster the complete transaction loop from product search to shipping confirmation with inventory updates, and assists in connecting to the market.

When we look to the key trends in the global automotive industry the move is tending to wards greater collaboration. Previously the automotive industry can best be described as a “producer-driven” (Built to stock) supply chain with multi-layered production systems that are organised hierarchically into tiers.2

The automotive industry and the logistics industry are evolving concurrently. Both industries are shifting towards customized, information based processes with a global scope. There is a growing demand for personalized goods to replace those that are mass-produced. Consumers clamor for goods that fit their needs and their specifications. As changes in automotive

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2 Andrea Bardi A1 and Nicolo Guidotti Magnani Pascale, 2011, Pages: 67 – 90
production and distribution occur, new logistics practices must be established. The logistics industry is being required to customize services to the supply chain demands of global companies that, in turn, need to evolve into companies that offer customized products to consumers. In the past decade, countless companies underwent the process of “globalization.” These companies have developed their international presence through mergers, acquisitions and collaborations. Services that were traditionally driven by physical assets and centered on domestically scoped, industrial activities are becoming full-service, global activities that are information driven. An industry focused on legacy systems technology and manually driven communication is shifting to an industry characterized by high visibility, a focus on internet based applications and a utilization of collaborative solutions. This new, information-driven logistics model is far more flexible to keep in tune with changing customer demands. Traditional asset-centered management models are not suitable for the massive scope of most companies. The new model is far more effective in streamlining the logistics needs of a company than its predecessor.\(^3\)

Build to Order, the Future of the Automotive Industry in a trend similar to that in the logistics industry, mergers and acquisitions are stimulating the global growth of the world’s largest automakers. In the past several years, many of the largest automakers have acquired, or merged with, foreign auto companies. As these companies grow, their strategies and business\(^4\) operations are evolving to succeed in a global marketplace. Consequently, traditional auto industry distribution practices are no longer optimal.

The complexities of globalization are compounded by the need to serve a more demanding customer base. Automotive consumers are intensifying their requirements. Increasingly, they are demanding products that fit their personalized specifications. Automakers are feeling pressure because there are more consumers demanding personalized goods. Traditional automotive industry characteristics will not meet increasing customer demands for a personalized experience. Typical automotive characteristics include: mass marketing, long delivery time, huge inventories, minimal customer contact, consumer compromises, and poor

\(^3\) M.J. Naude & J.A. Badenhorst-Weiss, 2011


Thomas Volling n, Thomas S. Spengler, 2011
delivery reliability. The new, developing automotive world will be defined by rapid delivery time, increased quality, and customer-centric relationships. As with many industries, the auto industry is increasingly driven by the need to improve and maintain customer satisfaction.

As a result, the need to optimize the emerging Build to Order (BTO) model has become a priority. Experts predict that within the next decade the auto industry will make a near-complete transition from an “off the lot” model to a BTO-type model. The industry will shift to a BTO model to improve profitability and customer responsiveness. Consequently, the way customers look for, and purchase, new autos will change dramatically. The auto industry will shift to a build-to-order model to improve its profitability and customer responsiveness, changing the way customers look for and purchase new cars.

One definitive statement can define the emerging auto industry BTO model: automakers must fulfill the need to deliver the right vehicle in the right time with zero inconvenience to the customer. Consequently, automakers are working to simplify and improve vehicle designs, reduce delivery times, and implement locate-to-order capabilities. This increasing demand of customers to get product of his own choice, short delivery time, high product quality and reasonable cost will create considerable pressure and problems to be addressed in each part of the automotive supply chain and finally big problem to be solved on the shop floor.

Here in this thesis it is aimed to look on problems created on the shop floor while addressing these ever increasing customer demands by using Model mix planning and assembly sequencing with SAP APO.
3. Supply Chain Management

3.1 Introduction

For a long time the focus in Logistic projects has been the optimisation of certain logistic functions, eg. The optimisation of the transportation and distribution structures. Usually small concern was given to the adjacent processes and the complete product portfolio. The supply chain management approach differs from this by grouping products with similar properties from a logistic point of view to a supply chain and taking all the processes in SCOR(Supply Chain Operations Reference) terminology: Plan, source, make, deliver per supply chain in one account.

![Supply Chain Operations Reference](image)

Supply chain management is the integration of business processes from the end users through original suppliers those provide products, services and information that adds value for customers.

Plan deals with demand and supply planning to assess supply resources, aggregate & prioritise demand requirements, plan inventory, distribution requirements, production, material & rough-cut capacity for all products and all channels and manage planning infrastructure, make/buy decisions, supply-chain configuration, long term capacity &resource planning, business planning, product phase-in/phase-out, manufacturing ramp-up, end of life management and product line management.

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5 Aigbedo, H., 2007, Pages 704–715
Source deals with sourcing/material acquisition (Obtain, receive, inspect, hold and issue material) and manage sourcing infrastructure (Vendor certification and feedback, sourcing quality, in-bound freight, component engineering, vendor contracts, initiate vendor payment).

Make deals with production execution (Request and receive material, manufacture and test product, package, hold and/or release product) and manage make infrastructure (Engineering changes, facilities and equipment, production status, production quality, shop scheduling/sequencing and short term capacity).

Deliver deals with order management (Enter and maintain orders, generate quotations, configure product, create and maintain customer database, manage allocations, maintain product/price database, mange account receivable, credits, collections and invoicing, ware house management, pick, pack and configure products, create customer specific packaging/labelling, consolidate orders, ship products), transportation and installation management (Manage traffic, mange freight, manage product import/export) and manage deliver infrastructure(Manage channel business rules, order rules, manage deliver inventories, mange deliver quality).
3.2 Approaches to structure Logistic processes

The main differentiator for supply chains is the production strategy, that is if the product is created according to the specific customer demand (Make to Order) or anonymous (make to Stock). The two approaches to structure the logistic processes within a company are make to stock and make to order approaches.

![Supply Chain Types Diagram]

**Figure 3.2 Supply Chain types**

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1. Make to stock: This production strategy has been used by all car manufacturers but now some are shifting from this production strategy. The production system of make to stock production is shown in Fig. 3.3. In this production system every shop is disintegrated and demands will be done not according to the present demand of the customers but by sales forecast, analysing the previous sales data. Here it is very difficult to produce different product variants according to customer demand.

Figure 3.3 Make to Stock production system
2. **Make to order**: This production strategy is gaining more attention from the car manufacturers since the shift from the traditional (Make to Stock) and fulfilling environment is becoming necessary. Widespread increase in product variety and the simultaneous emphasis on shorter order-delivery times, and lower costs, is forcing manufacturing firms to consider alternatives to make-to-order modes of production. A common product platform is built to stock and then differentiated into different products once demand is known. Here in Fig. 3.4, it is tried to illustrate the coordination of Metal Shop, Body Shop, Paint Shop, Assembly Shop and Quality by the Production Control department. In this case one can update production rates and plan resources according to the demand of customers.

![Figure 3.4 Make to Order production system](image-url)
4. Automotive Supply Chains
4.1 Introduction

The present make trends in automotive industry shows, the customer request for a specific product, the need for short time delivery, high product quality are increasing tremendously. The increase in demand of specific car variants and the amount of additional parts according to customer’s demand is creating a big problem to be solved on the shop floor. To satisfy the ever-growing need of customers using the available/innovative technological approaches is inevitable to stay competent in the market. These demands of customers are also giving a great push for car manufacturers to change their production strategy.

Following the evolution in the computer industry, quite a lot of car manufacturers currently intend to move from a built to stock oriented production of standardized cars towards a rather customized built to order production and to realize short delivery times, high delivery reliability and a fast responsiveness. Mass customisation, that aims at offering customized products in a high variety but for still low prices and within short delivery times, gains increasing importance in various branches of business and, in the meantime, also captivates the automotive industry. 7

Example: The BMW Group, for example, spent 55 million on its new European online-ordering system to cut order to delivery times by 20 days on the average. At the same time, BMW offers up to $10^{32}$ variants (at least theoretically), several thousands of them actually being demanded. Other manufacturers also declared their intention to decrease order to delivery times from an average of 40 days to about 15 days and try to make the transition from build to stock to build to order that has successfully been demonstrated by the computer industry, and first and foremost by its paragon Dell.

The transition to built to order in the computer industry caused a reorganization of planning processes and led to an increased use of Advanced Planning Systems i.e. of computer based decision support systems, which | at least partly | rely on sophisticated methods of Operations Research. Thus the questions arise, whether and how the transition of the automotive industry changes their respective planning tasks and planning processes, and to what extend planning and Operations Research methods are and will be affected.

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7 Herbert Meyr, 2002, Pages: 1-2
4.2 Automotive Supply Chain Characteristics

Automotive supply chains can be seen in different ways according to the area of focus of study. Here we discuss the characteristics of an automotive supply chain with two attributes, functional attributes and structural attributes. Since the main aim of the thesis lies on the production system (Model mix planning and assembly sequencing) the functional attribute will help us to see the significance of sequencing in the shop floor by giving a clear understanding the sources of imbalance and pressures created on the production system from the overall supply chain perspective.8

1. **Functional attributes**: discusses on sales type, distribution type, production type and procurement type of a supply chain, which have to be specified for each member of the supply chain separately. In the functional attributes of the production system in a car assembly we will find the main aim of this thesis, which is the Model mix planning and assembly sequencing.

2. **Structural attributes**: describes the relations between different, legally separate members of a supply chain.9

4.2.1 Functional attributes

The sales type relates to product and market characteristics. Cars are sold to final customers either directly via sales subsidiaries of the car manufacturer or indirectly via legally separate retailers. The bill of materials is strictly convergent, i.e. assembly processes are predominant. Cars often are thought to be standard products. However, in the premium segment of this line of business, there is a high degree of customisation. This is caused by the high number of features that the customer has to specify, for example obligatory equipment like the colour of the car and type of upholstery or optional equipment like air conditioning or a navigation system, to name only a few. In the following both obligatory and optional equipment are just referred to as options. A car manufacturer usually offers several series of cars (e.g. the E series or C series of Daimler Chrysler), which again differ in several body-in-white variants (coupe, convertibles, etc.). Cars are sold globally. Due to different regulations of law and cultural preferences, also country specific variants (e.g. with respect to the steering or

8 Herbert Meyr, 2002, Pages: 1-2
9 Herbert Meyr, 2002, Page: 3
emissions) are required. Not every customer needs his car immediately. The order lead time desired by a final customer is normally distributed with a mean value of 4 to 6 weeks.

The sales organization and distribution network of a car manufacturer have a divergent structure, which comprises several stages like the central sales department of the manufacturer, sales persons responsible for different world regions (also at the headquarter), sales companies in different countries or local areas and a rather high number of further retailers and sales subsidiaries. Transport times to different markets vary between a few days (by truck to regional customers) and several weeks (overseas transports). This type of customized premium cars can only be assembled to order, i.e. there has to be an order available either by the final customer, a retailer or a sales department of the manufacturer that specifies the options of the car.

Current supply chain management initiatives in the automotive industry try to increase the share of final customers' orders and to decrease the share of retailers' and sales departments' orders. Thus the share of retailers' orders usually is rather high and quite often the retailers have to bear the risk of obsolete stocks. Commonly, manufacturer and retailers communicate in two types of interaction rounds:

In the first one, a retailer sends his mid-term requests for cars to the manufacturer. Both negotiate the number of cars (so-called ‘‘quota’’) the retailer will get during the next year. Usually, this negotiation process is clearly dominated by the manufacturer so that due to the preferences of the manufacturer the agreed quota may be less or even higher than the original requests. Since these quotas are, for example, defined for the next year on a monthly basis, only body-in-white variants and the type of engines are considered, but the options are not specified at this point in time.

In a second round, about three to five weeks before planned production, the retailer has to specify the options for all cars of his quota, which are due and have not been assigned to final customer orders that had arrived in the meantime. From a retailer’s point of view, these cars are built to stock cars, based on a sort of forecasting process for options. From the manufacturer's point of view, an order of the retailer exists, thus justifying the term built to order. From a supply chain's integrated point of view, the number of cars, built to stock,
should be decreased in any case in order to better adjust the supply chain to final customers' demand.

The production system in a car assembly plant usually comprises the four stages pressing of metal or aluminium sheets, welding the body-in-white from the moulded sheets in the body shop, painting it in the paint shop and final assembly, where painted body, engine, transmission and the further equipment are brought together or built in.

Unlike the other three shops (Metal shop, Body shop and Paint shop) the final assembly shop consists of several production lines with. These production lines are a lot of serially arranged assembly stations. When one looks the production of one or two types of car variants produced on these production lines, which consist of many assembly lines, it may seem simple to schedule the production lines (The resources, which can be man power or machineries). But as the number of varieties increase, according to each customer demand, consequently the type of load distribution will be affected. Some stations will be highly overloaded, since almost all of the variants should have to pass through these stations and some other stations will be under loaded, since they are not obligatory or ordered by most
customers. Because of these the scheduling problem will get complicated as the number of variants and the specific built in parts, ordered by customers increase. In the later section of this thesis we will see how we can solve this problem using `SAP APO` planning software. In the medium and short term planning we can use some organizational methods, like swing persons, over time and some other measures but this one should not be taken as a long term solution since works.

For the final assembly one or several production lines are used. A production line consists of quite a lot of serially arranged assembly stations, between which cars are conveyed with a fixed belt rate (Takt based scheduling). The processing time at an assembly station depends on the option chosen for the car to be assembled. Therefore, the overall utilization of a station is determined by the sequence in which cars orders are assembled on a line (model mix). If too many cars requiring the same options are following one another, some of the stations may be overloaded whereas others are under loaded. Thus a balanced model mix has to be found, almost equally utilizing the various stations of an assembly line. Often assembly lines are dedicated to a particular car series. However, sometimes more expensive lines are able to assemble several series at the same time, in order to flexibly react on demand variations. Assembly lines can only be run profitably, if a certain minimum utilization per assembly station is guaranteed. Strategic planning tries to adapt plant and line capacities and thus implicitly this minimum utilization to customer demands in the long term. In the medium and in the short term working time can be varied in a limited way, e.g. by working time accounts, overtime or usage of swing men.

However, if in the medium term customer demand is lower than this minimum utilization and the working time flexibility is exhausted, the surplus production has to be pushed into the market. If, on the other hand, customer demand is temporarily higher than production capacity, the scarce production quantities have to be rationed. Altogether, this technological inflexibility is one of the reasons why the above mentioned quotas are used to balance capacity and demand in the medium term. As we have seen in the Production system the assembly line will take parts that are procured from different production sites. To proceed with the procurement process the procurement network with several hundreds direct and enormous indirect number of suppliers should be coordinated. Because of the high power of car manufacturers supply lead times usually are short and reliable except for hidden bottlenecks in the procurement network. For the delivery of incoming goods normally several
transport modes are applied. Voluminous and expensive components are as far as possible delivered just in time at the day of assembly, partly even directly to the assembly line and thus arranged in the sequence of planned assembly sequence-in-line supply. The remaining incoming goods are collected by regional carriers, consolidated and brought to intermediate warehouses of the car manufacturers, which are close to their assembly sites.

4.2.2 Structural attributes

Automotive supply chains are characterized by a convergent flow of material upstream of the assembly plants of the car manufacturer and a divergent of finished cars downstream. An automotive supply chain is difficult to coordinate, because not only production capacity and man power, but also incoming goods may turn out to be bottlenecks. For reasons of flexibility, at least a few car series can usually be produced at several assembly plants, alternately. Because of these constraints, the promised delivery dates cannot always satisfy the expectations of the final customers. Furthermore, final customers need a reliable delivery date because important further activities like (selling the old car, making money available) have to be synchronized with the arrival of the new car. Thus, "order promising" not only has to aim at setting a delivery date close to the customer's wishes, but also at promising a reliable date considering as many of the above constraints as possible.\textsuperscript{10}

\textsuperscript{10} Herbert Meyr, 2002, Page: 6
5. Production Planning in Automotive Industry

To work various planning tasks of automotive supply chains quite a lot of planning units must be involved. These planning tasks and the respective decisions can be assigned to several planning levels (e.g. strategic, tactical and operational) comprising different planning horizons (e.g. long, mid and short-term).

The longer the planning horizon, the more unreliable the input information, that is the basis for making a plan, and the more aggregate the results of planning have to be. On the other hand, the shorter term planning is, the more detailed the decisions can be and have to be. Depending on the planning horizon and the lead time necessary to make a certain decision. Therefore, from a manufacturer's point of view, one may distinguish between forecast driven (long & mid term) planning and order driven (short term) planning.

5.1 Forecast driven planning

![Diagram of Forecast driven Planning](image)

6 Fig. 5.1 Overview of Forecast driven Planning

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11 Herbert Meyr, 2002, Page: 8
As it is shown above, Fig. 5.1 summarizes the forecast driven planning activities. Planning tasks are marked by rectangles; arcs illustrate the information flows in between. From the bottom to the top, the level of aggregation and the planning horizon are increasing, the frequency of planning is decreasing, however. The planning tasks are roughly assigned to the logistical functions procurement, production, distribution and sales, again.

5.1.1 The annual budget planning

It determines the overall monetary budgets of the car manufacturer's departments and assembly plants for the next year. For this, production plans for the respective plants and the sales plans for the respective sales regions have to be calculated, too. This is done once per year, for the next year, by deciding about production and sales quantities of car models (per plant and world region, for example) on a monthly basis. The overall yearly quantities can be considered as volume goals of the next year for both sales and production. From these, the expected production costs and earnings can be derived outcome goals.

A further result of the annual budget planning is the usage or setting of additional capacities, as far as these can still be influenced on a mid term basis. Because of the long lead times (e.g. two years or more to install an assembly line or a plant), usually capacities of production resources are adapted to customer demand in the long term and thus are a concern of strategic planning. However, agreements about the extent and flexibility of the yearly working time, for example, are also tasks of mid term planning. A lot of further constraints have to be respected like potential bottlenecks of suppliers, model mix restrictions (capacities of crucial options, minimum utilization) and upper or lower bounds of the sales in certain markets. Lower bounds, for example, result from strategic directives about the presence in important markets, upper bounds may be due to marketing analyses about final customer demand.

5.1.2 Demand Planning

These are used as an input data for the annual budget planning. (See Fig. 2.2) Since budget planning has to decide about car models on the one hand and to anticipate potential bottlenecks of suppliers on the other hand, the component demand needs to be estimated, too. Demand planning will give us this data since they are forecasts for final customers' demand. These are made on basis of historical sales data, of some few, already known and fully specified orders from final customers (e.g. car rentals), of the retailers' annual requests for models, of the sales companies' decentralise knowledge about the local preferences of their
customers (requests of regions) and on basis of information about marketing capabilities to influence final customer demand. One way to do this is to forecast attach rates directly, i.e. to calculate the probability that a certain option or even component is demanded (in a specific customer region) and to multiply it with the total number of car models planned (for this region). However, sometimes the mix of options chosen for a respective car is also of interest. Then, because of the high number of options to be specified, a few important representatives for fully specified cars are selected and their potential sales volumes are forecasted and planned in annual budget planning, for example. From these, the component demand can be derived using the Bill Of Materials (BOM). The concentration on a few representatives makes planning easier, but models the diversity of car variants only vaguely.

5.1.3 Program planning

It is similar to the annual budget planning. Here also Production and sales plans have to be determined and coordinated. However, both now require a higher level of detail (e.g. weekly instead of monthly quantities) and they are not used to derive budget goals any further. The planning horizon of a monthly rolling horizon planning varies between three months and one year. Nevertheless, only the weekly quantities of the first month or the first two months (depending on the lead times of planning) are put into practice. Input data are sales forecasts for models and forecasts for attach rates or representatives. Because of the high share of final customers' orders, that is available for this shorter planning period, these monthly forecasts are more reliable than the annual forecasts used for budget planning. Further input data are the production and sales quantities per month that have been agreed upon in the budget planning, or the respective volume and outcome goals (e.g. per year). One objective of the program planning is to meet these targets as close as possible in the short term. Constraints to be respected are quite the same as were relevant for the budget planning. However, again a higher level of detail is necessary. For example, capabilities to adapt working times are more restricted now, e.g. the shift pattern can only be varied with respect to a given annual working time.

Results of the program planning are updated and more detailed (e.g. weekly) production plans of the assembly plants and sales plans. The latter ones include the quotas for the different sales regions. Because of the above mentioned constraints, these quotas may exceed or fall below the requests for car models, originally demanded by the regions. A similar setting of
monthly instead of weekly quotas for sales regions may possibly also be part of the annual budget planning.

5.1.4 MRP (Materials requirement Plan)

The production plans for representatives of car models, which are a result of the annual budget and program planning, are the basis to derive the component demand in a further material requirements planning (MRP) procedure. For this purpose the planned production quantities might be multiplied by steady BOM coefficients, if representatives of fully specified cars have been used, or by attach rates. In the latter case special BOM structures, also considering dependencies between several options, are required for calculating the component demand. This component demand is communicated to the first tier suppliers as a preview of the quantities to be delivered within the next months. As the options of the cars are just specified for the 3 to 5 weeks before and since the share of final customers' orders decreases rapidly for longer lead times and, this component demand becomes more and more unreliable, the longer the forecast horizon is. Usually, the component demand is communicated to suppliers on a weekly basis for the month(s) being frozen in program planning and on a monthly basis, afterwards. Updates of the previews can be synchronized with the rolling horizon frequency of program planning, whereas budget planning is only done once per year.

5.1.5 Allocation Planning

On the sales side, the allocation planning has to allocate the aggregate quotas, which are known as a result of the budget planning on a monthly basis and as a result of the program planning on a weekly basis, to the lower levels of the sales system. Depending on the organizational structure of the car manufacturer, this planning task may occur on several hierarchical levels, e.g. First an allocation of quotas of world regions to different countries, and afterwards an allocation of these more detailed quotas to the countries' respective retailers and sales subsidiaries.

As an example, in the following only the relation between world region countries is considered. After the annual budget planning, the respective monthly quotas (sales plans) of the world regions have to be allocated to the countries with respect to their original requests. If the requests cannot all be satisfied, it has to be decided, whose demand will only partly be fulfilled. This shortage planning may follow some predefined rules (so called 'fair share
Rules’), which, for example, might reflect the purchase behaviour of a country in the past, or more or less be based on negotiations between representatives of the world regions and of the respective countries. Furthermore, a region has to balance the deviations of the countries' actual demands from their former requests between all the different countries assigned to the region. For this purpose, the region may also call for and hold a regional pool of cars, originally not having been requested by one of the countries. A similar planning task occurs when later on the updated weekly quotas of the program planning also have to be allocated to the countries. However, in this case the monthly quotas of the budget planning have to be considered, too. Furthermore, at this later point in time final customers' demand is more precisely known because of the higher share of final customers' orders, so that the above mentioned balancing mechanisms play an even more important role. If a region's monthly quotas cannot be met because deviations of final customers' demand are too large, at least the yearly volume and outcome goals ought to be achieved.

### 5.2 Order driven planning

![Order driven Planning](image)

7Fig. 5.2 Overview of order driven Planning\(^\text{12}\)

\(^{12}\) Herbert Meyr, 2002, Page: 11
In the forecast driven planning we have been seen planning tasks, which mainly build on forecasts for options. In other words, only a few fully specified orders are known at the time of planning. In this section planning tasks will be considered which are exclusively triggered by fully specified orders, either of final customers or of sales subsidiaries and retailers. Figure 5.2 gives an overview of these orders driven planning tasks and their interrelation.

Direct buying of cars via the Internet is not (yet) worth mentioning. Normally private customers order their cars via the sales subsidiaries or retailers of the car manufacturer. The respective sales personnel tell the final customers the expected delivery dates of their desired cars. Usually, a granularity of weeks is sufficient for the customer, who e.g. has to provide the money on time and to synchronize the delivery with the selling of his used car. Thus order promising, i.e. promising (soon and) reliable delivery dates to the customer, is an important task. If a free quota of the sales subsidiary or retailer is available, the final customer gets his desired delivery date promised. Otherwise, the next free quota is recommended or a standard delivery time is proposed, if quotas are not available in sufficient detail. The customer may accept the promised date, change the options of his desired car or even the model type in order to get an earlier delivery date, or try his luck with another retailer.

Furthermore, retailers and sales subsidiaries have to specify the options for that part of their quotas that has not been filled up with final customers' orders until the agreed date of specification. In order to shorten the days of inventories at the retailers' sites, the desired options of potential customers have to be anticipated as precisely as possible. Because of the rather small number of customers and large number of options, this is an almost unsolvable problem for a single retailer. Thus, central support of the manufacturer for these decentral forecasts of the retailers and some suggest even a central pool of built to stock cars.

Traditionally, these fully specified orders are collected by the respective sales organization, responsible for a certain retailer, and sent in bulk (e.g. all orders of a week) to the next higher level of the sales hierarchy. A central order management department of the car manufacturer finally has to select an assembly plant, able to produce the car model requested by a certain order. This plant assignment has to consider the production quantities and capacities per plant, that have been agreed upon in the program planning. If the actually requested car options significantly deviate from the ones assumed within program planning (e.g. when anticipating bottlenecks of components or model mix constraints), some orders have to be fulfilled earlier
and others have to be delayed. The plant assignment also roughly decides about the distribution mode, e.g. which traffic carrier (water, rail, and road) has to be used.

5.3 Assembly sequencing and model mix planning

The specific requirements of the automotive industry (e.g. several assembly plants, model mix constraints) are should be dealt one consistently to fulfil the demand on the time. Therefore, mixed model assembly line sequencing should be done with respect to given due dates of orders. This helps us to calculate detailed sequences of cars for a single assembly line. In section II of this thesis this will demonstrated using SAP APO planning software with a case study. Thus, the model is rather designed for the short term line sequencing than the more aggregate plant assignment. However, the problem of early or late demand fulfilment in the automotive industry is at least generally addressed.

After this assignment, the decentralised short term production planning departments of the assembly plants have production orders available, that ought to be assembled within (or up to) their pre defined week of production (ideally still the promised week minus a standard lead time for delivery to the respective customer). The shorter term planning is, the more restrictive the model mix constraints are. Thus, the line assignment & model mix planning has to distribute the production orders among the possibly parallel assembly lines and to assign days of production to the orders. Doing this, the most important model mix constraints (e.g. at a maximum 350 air conditionings per day") have to be considered, but the assembly sequence of a day is not yet determined. The next question is how can we solve the assembly sequencing ("Master Sequencing")? Here we can follow the further aggregation of individual orders to families of cars for the reason of complexity. In the following section we will see how can we solve and modify continuously, as it is demanded, the planning task using the SAP APO software.

The frequency of planning depends on the frequency in which production orders are sent to the plants. If this is, for instance, done weekly, a weekly line assignment & model mix planning should be sufficient as long as no extraordinary events happen. The planning horizon is limited by the committed dates for the specification of options, but usually equals several weeks. On a limited scale, standby and swing men can help to adapt capacities of the assembly lines to the model mix requested.
As compared to mid term planning, car options are now known with a high reliability. Since the daily assembly buckets are also known as a result of the line assignment & model mix planning, the daily demand of components can directly be derived. For components and material, that are collected by regional carriers and temporarily stored in an intermediate warehouse, an MRP & lot-sizing procedure is appropriate that balances the trade of between inventory holding costs and digressive transport costs of the regional carriers and determines adequate supply frequencies. This is even more important if a single supplier serves several assembly plants at the same time. In this case, the trips to the supplier should be coordinated, too. Thus the respective assembly plants have to synchronize their delivery frequencies and days of delivery. Usually, it is sufficient to determine a regular supply pattern in the medium term. To calculate short term procurement lots, the respective daily demands of components, exploded daily buckets of production orders, then have to be summed up for all the days up to the next scheduled delivery.

The daily buckets of the line assignment & model mix planning are also guidelines for the daily sequencing of the assembly lines. Here, the sequences of the production orders on the final assembly lines are determined on a rolling horizon basis with a planning horizon of one to two weeks. The level of detail again is higher than in model mix planning. Now all potential bottlenecks have to be considered, for example, the availability of all of the components and distance restrictions of the lines like, no two cars with air conditioning are allowed to follow each other. For this reason, sometimes the earlier assignment to days of production cannot be maintained. However, is should be avoided to postpone an order to another week than the planned and promised one. To use swing men or to work during lunch breaks again are short term measures to extend capacity.

Undoubtedly, most scientific research on planning aspects of automotive supply chains has been done in the fields of balancing and sequencing mixed model assembly lines. In the sequencing literature, usually it is assumed that orders have already been assigned to a certain period (e.g. a day) of production, so that promised due dates need not to be considered any further. The various sequencing approaches differ with respect to their different objectives. Besides cost oriented objectives, mainly time related or Just In Time objectives and combinations thereof are pursued.
JIT objectives attempt to smooth the material supply at the stations in order to keep the inventory of components constantly low. The usage rates of components are either levelled directly or, in case the cars require a similar number and mix of components, the mix of cars is levelled instead. Thus both time related objectives and JIT objectives directly address the model mix constraints discussed so far. The car sequencing problem allows to model the above mentioned minimum distances between orders with the same options and further separation rules like a maximum number of identical options within a car sequence of predefined length.

There again are some decisions to be made concerning the deployment of the finished cars. For example, the actual carrier has to be chosen, and transport frequencies (how often to deliver to a retailer) and vehicle routes (sequence of retailers within a tour) have to be determined. Some of these tasks are in the planning domain of logistic service providers. The daily buckets of the model mix planning give a reliable preview of the quantities to be delivered. Analogously, daily delivery dates can be calculated and promised on basis of the model mix planning. Since such promises should not be revised later on, final customers' orders usually have a higher priority than retailers' orders within model mix planning and sequencing. However, this preference scheme of course is valid for all of the order driven planning tasks discussed within this section.
6. Production Planning with APO
6.1 Introduction to Supply Chain Management with APO

The supply chain consists of retailer, wholesaler, distributor and factory. Each around the customer’s order is placed at retailer and, the retailer places his order at the wholesaler and so on unto the factory. The factory finally creates production orders. Here we can see the importance of transparency in the supply chain. For this matter the Beer game illustrates the importance of transparency in a playful way.

The goods flow is modelled by deliveries from the factory to the distributor, from the distributor to the wholesaler and so on to the customer. Each delivery requires goods movements across two fields and takes therefore two rounds. The production (the time between the creation of the production order and the goods receipt at the factory) requires three rounds. Therefore, the customer orders after passing the through the process as shown in fig.6.1, the Beer game, will have a different (exaggerated) arbitrary impression due to the lag between placing the orders and receiving the supply, the insecurity about the future orders of the partner on the demand side and the insecurity regarding the stock outs at the partner on the supply side usually cause over reactions for the own orders. Finally this will destabilize the supply chain. It is evident that a visibility of the customer demands across the supply chain helps to prevent this kind of destabilization of the supply chain.\

To improve the transparency both a change of the processes and a system which enables the data transparency is necessary. To solve this problem a planning tool to increase the transparency is necessary. But attention should be paid that a successful supply chain management project requires more than the implementation of a planning tool. Eg. SAP APO

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13 Joerg Thomas Dickersbach, 2008
6.2 Introduction to APO Modules

From a company’s point of view a supply chain usually consists of customers, distribution centers, plants and suppliers. There might be several levels of distribution (e.g. regional and local) or several levels of production, if one plant produces the input material for another plant.

The most common supply chain processes are, sales order taking, back order processing, forecasting and demand planning, distribution planning, replenishment, production planning & detail scheduling, production execution and procurement. APO consists of different modules with different levels of detail. These modules are:

i. Demand Planning (DP),
ii. Supply Network Planning (SNP) including Deployment Functions,
iii. Production Planning and Detail Scheduling (PP/DS),
iv. Available to Promise and
v. Transport Planning & Vehicle Scheduling (TP/VS).

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14 Joerg Thomas Dickersbach, 2008, Pages: 2-3
The supply chain processes identified above are generally modelled in the APO modules as shown in Fig. 6.2. Production Planning and Procurement, to a certain extent even Distribution Planning are modelled either in both SNP and PP/DS, in SNP only or in PP/DS, depending on the requirements for the processes.

From a supply chain project point of view fig. 3.2 represents an implementation with the full scope of APO. There are some companies which apply APO this way and even implement the complete scope at once. More often only a part of the scope is implemented, either as a first step or because this part is sufficient to satisfy the current needs. The advantage of keeping the scope of the implementation small lies in getting early results and having shorter project duration.

Most implementations have only Demand Planning in scope since it is both technically and organizationally the part with the least complications. Other common architectures are

i. Available to Promise (ATP) for availability check across several plants,

ii. PP/DS for scheduling and sequence optimization,

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15 Joerg Thomas Dickersbach, 2008, Page: 10
iii. PP/DS for finite production planning,
iv. DP & ATP for demand planning and availability check of allocations,
v. DP & SNP for demand planning, distribution planning and replenishment,
vi. DP, PP/DS & ATP if there is no focus on distribution in the supply chain and sourcing decisions are either irrelevant or made using rules based ATP.

These are only some of the possible or even of the realized architectures.

### 6.3 APO Architecture

APO consists technically of three parts: the database, the BW datamart and the live cache. Since BW does not support the client concept, neither does APO, with the exception if only those modules are used, which have no connection to the BW part.

![Fig. 6.3 APO System structure](image)

The BW datamart consists of info cubes and is technically the same as in the BW system. The live cache is basically a huge memory where the planning and scheduling relevant data is kept to increase the performance for complex calculations. Though there is technically only one

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16 Joerg Thomas Dickersbach, 2008, Page: 12
live cache per installation, the data is stored in three different ways depending on the application:

i. as a number per time period (month, week, day) and key figure (time series),
ii. as an order with a category, date and exact time (hour:minute:second) and
iii. as a quantity with a category and a date in ATP time series.

As fig. 6.3 the according parts of the live cache are referred as time series live cache, order live cache and ATP time series live cache.

Demand planning uses much of the BW functionality and relies on the info cubes as a data interface to any other system, R/3, BW or flat tile. Therefore the historical data is always persistent in an info cube. For processing the data is written into the time series live cache.

SNP and PP/DS use mainly the order live cache; though SNP is able to access the time series live cache as well, since there are many structural similarities between DP and SNP. ATP relies on the ATP time series live cache.

6.4 Production Planning Process for repetitive manufacturing in APO

The following diagram, fig.6.4, shows the production planning process for repetitive manufacturing for configurable (make to order) and non-configurable (make to stock) products with APO.
Parts dealt in this thesis

Parts not dealt in this thesis

11 Fig. 6.4 Planning Process of Repetitive manufacturing

(Make to order or Make to stock) in APO

This process describes how to execute Repetitive Manufacturing in APO on the basis of the integrated Product and Process Engineering (iPPE). Scheduling in APO using this process is carried out as takt-based scheduling (it will be discussed in the following section).

As shown on fig. 6.4 the first step to proceed with planning features is to maintain master data in APO. The master data for planning is the iPPE structure, which comprises all the product structure, process structure and factory layout. Since the components and the processes in Automotive industry are incredibly too much, we have to develop a means to organize them and when need arises it will be simple to identify them following the proper path. Therefore before developing the iPPE structure we have to develop a classification system, a system that allows using characteristics to describe all types of objects and to group similar objects in classes - to classify objects, so that they can be found more easily later. Then when the need
arises a person can use the classes to help to find objects more easily, using the characteristics defined in them as search criteria. This ensures that one can find objects with similar or identical characteristics as quickly as possible.

6.5 Classification System

The classification system allows classifying all types of objects. SAP APO has predefined a number of object types (for example, materials, and equipment). There are three steps to setting up a classification system, which include Characteristics, Classes and Assignment.\footnote{APO online documentation, 2010}

6.5.1 Defining the Properties of Objects (Characteristics)

Characteristics are used to describe the properties of objects. They can be created in SAP APO or SAP R/3. But in this case I have created them in SAP APO.
i. **Body Styles** (Values: Sedans, Roadsters, Coupes and Wagons)

![Image of Body Style Characteristics]

**Fig. 6.5** Body style characteristics and the respective values of the case study


![Image of Engine Power Characteristics]

**Fig. 6.6** Engine Power characteristics and the respective values of the case study

iii. **Engine Cylinder Types** (Values: V_6, V_8, V_12)

![Image of Engine Cylinder Characteristics]

**Fig. 6.7** Engine cylinder characteristics and the respective values of the case study
6.5.2 Object types, types of class & Classes

The class type is a central concept in the classification system. The class type determines how classes are processed, and how objects can be classified and retrieved in these classes as shown in fig. 3.8. Here in my case study I have used a class type of 300 (Variant), because I am dealing with the car variant configuration.

![Diagram of Object types, Class types, and Classes](image)

According to SAP APO, Class types 001, 300, and 200 are defined for materials. All materials can be classified with class type 001. Class type 300 is for variant configuration. Class type 200 is for classes that are used as class items in bills of material. You can classify the same materials separately in these class types. 18

The class type determines the following:

i. Which object types should be assigned to a class

ii. Which class maintenance functions you can process

iii. Whether one can classify objects in more than one class

iv. Which class statuses, organizational areas, and text types are supported in class maintenance functions

v. Whether one can use engineering change management for classification

vi. Which filter functions you can use to restrict the search result

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18 APO online documentation, 2010
After defining class types for a specific object type, such as materials, we can use then classes of this class type to classify objects of this object type.

Classes are needed to classify objects and characteristics are assigned to the classes. In the case study I have used class Class_2004C for the Master data with five different variants. This Class allows me to group objects together according to criteria that I defined.

In the Factory’s Products classification system instead of assigning all products in to one class we can set up our classification system as a hierarchical structure. This will make us to target the searches for our objects. For example, instead of classifying all of the Passenger cars, Trucks and Buses in the Automotive Industry in one class for automobile or car, we assign other classes to automobile or car, such as Passenger Cars, Trucks, Busses, Vans and Camper vans and other classes to these classes, if required.

As shown in fig.6.9 the hierarchical structure of the classification system simplifies the search of a specific product/object. One can start his/her search for specific cars with class Cars/automobiles, and continue his/her search down the different levels of the hierarchy.

\[\text{Fig. 6.9 Classification system as a hierarchical structure}\]

6.5.3 Assigning Products/Objects

Once classes those are required for classifications are created, then we can assign Products/objects to these classes. We use the characteristics of the class to describe the objects
we classify. This completes the data one requires to use our classification system. A person can then use our classification system to find objects that match the criteria he/she requires. The following graphic is an overview of the functions of the classification system.

17 Fig. 6.10 Overview of the functions of Classification System

Once the classification system is set up one can use it to find certain products/objects. To do this:

i. Find a class in which objects are classified

ii. Find the object(s) you require in the class

When we use classification to find Products/objects, we use the characteristics as search criteria, and the system compares the values we enter with the values of the classified objects.
6.6 Maintaining Master Data

Master data for production planning and scheduling can be maintained in two different ways.

i. Maintaining Master data with production process model (PPM)
ii. Maintaining Master data with Integrated Product and Process Engineering (iPPE)

In the following sections, 6.6.1 and 6.6.2, we will see the advantages, disadvantages and scopes of the two methods of maintaining master data.

6.6.1 Maintaining Master data with production process model (PPM)

This process is advisable for planning processes in APO on the basis of production process model (PPM). This process is suitable for non-configurable products (make to stock) for which you create simple lines and routings with only a few operations. Here, lead time scheduling is carried out.

The shift from the make to stock to make to order in automotive industry will decrease the importance application of this modelling process. Moreover, the modelling is not advisable for complex shop organizations and processes with high volume of order and production is make-to-stock, that is, with no direct link to any particular sales order.

Manufacturing with the Production Process Model are advisable if a pure make-to-stock products are manufactured and produced in large quantities of the same product using the same production process in unlimited lots. This means production is planned and executed with no reference to the sales order. The planned independent requirements are created in Demand Planning in APO (APO Demand Planning). Incoming sales orders are delivered from warehouse stock and the sales order quantities consume the planned independent requirements quantities according to the selected planning strategy. Planning is based on these two requirements (sales order quantities and planned independent requirements).

The disadvantages of using this process are:

i. Planning any configurable products is not possible.
ii. When planning, APO does not take the various change statuses of the master data into account, which you maintain in the system.
6.6.2 Maintaining Master data with Integrated Product and Process Engineering (iPPE)

This Master data maintenance enables to handle multiple variant products which are produced on takted production lines. In this case, takt-based scheduling is used when planning. Planning and production backflushing in APO are executed on the basis of the integrated Product and Process Engineering (iPPE).

Using the iPPE structure we can manage data for configurable (make to order) products. This process is suitable for configurable products, which are manufactured with reference to the sales order (make-to-order repetitive manufacturing). The sales orders are used as the basis for planning. That is, the planned orders for the product ordered by the customer and for important components are assigned to the account of the sales order for which they are required. However, it can be used also for non-configurable products where production is carried out as make-to-stock production, that is, with no direct reference to any sales orders. Here, production is executed with direct reference to the sales orders.

The biggest advantage of the iPPE modelling structure lies:

i. it can be used for make-to-stock production and for make-to-order repetitive manufacturing with configurable products

ii. complex shop organizations, processes and many product variants can be modelled easily in a single model.

iii. the planning procedure is not based on lead time scheduling, like the PPM, but on takt based scheduling.

The disadvantage in working with this process is it cannot use pull lists, event-controlled kanban or kanban with planned orders for the products.

6.7 iPPE Structure

Integrated Product and Process Engineering (iPPE) is a new form of creating and processing master data for design, construction and production. The iPPE structure collects all the data for an entire product life cycle in one integrated model. It is particularly suited to products with many variants. One can use iPPE to document data, and later reuse and update it, from early phases of the product’s research and development process. You can represent a complete production model because iPPE allows you to keep the master data for Bill of
Materials (BOMs), routings, and line design in one model. It is particularly suited to repetitive manufacturing.

The Functional structure data can be maintained at the beginning and later to fill with more data at later stages in the product development, thus representing the whole product life cycle. The iPPE structure is consisting of Product structure, Process structure and Line design. The product variant structure and assemblies can be used to maintain BOM data for configurable and non-configurable materials, the process structure can be used to maintain routing data, and the Line design can be used to maintain the structure and setup of your production lines. The use of iPPE is particularly recommended for products with many variants that are configured-to-order and produced on takted production lines.

The structure of Integrated Product and Process Engineering (iPPE) is basically made up of abstract elements, which are especially developed in Customizing for specific applications. The basic elements of iPPE are:

1. **Nodes**: represent general elements in the three application models that form iPPE.
2. **Variants**: is the concrete instance of an iPPE node
3. **Alternatives**: they lend more flexibility to the product structure as they are used to represent alternative assemblies of a part to be produced. An alternative groups several relationships that point to subordinate nodes. Alternative (or mode) in the process structure or iPPE routing are used to define how and where an activity is executed.
4. **Relationships**: link the iPPE objects/elements to form the structure.

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19 APO online documentation, 2010
The applications of iPPE are:

i. Product structure for reproducing BOM data
ii. Process structure for reproducing routing data
iii. Factory layout for reproducing production lines
The iPPE elements can be assigned to different application object types. The assignment defines which task an element has in iPPE.

i. The application object type ACT is for the *process structure*, or routing, in iPPE. The process structure describes and structures the activities needed to manufacture the product.

ii. The application object type CMP is for the *product structure* in iPPE. The product structure describes the structure of a product.

iii. The application object type FLO is for the *factory layout* or line design in iPPE. Line design represents the structure of the production equipment.

iv. The application object type COL is for the colors in iPPE.

The objects are assigned to one of the levels in iPPE. The three levels are:

i. Access level

ii. View level

iii. Structure level

The assignment allocates the object its function as the header of a structure, a view on a structure, or a part of a structure.

The three different structures (product structure, process structure, and factory layout), which constitute Integrated Product and Process Engineering, to create the overall structure for the material that is to be produced, are linked by an access object. For shop-floor-orientated manufacturing, access object links the product structure to the shop-floor-orientated process structure. The iPPE access object is the central object for accessing material requirements planning with the Rapid Planning Matrix for a product in the Advanced Planner and Optimizer (APO).
6.7.1 iPPE Product Structure

The iPPE product structure aims to give a redundancy free description of products or product families that have many variants, and to provide a consistent data basis for all enterprise areas that work with the product structure or parts of it. It provides an integrated data model that is the basis for efficient IT management of the product structures. It can be used to adequately portray both the product creation process (with the main focus on Product Data Management) and also production (the main focus being requirements planning).

The iPPE product structure is used to configure products with many variants and a large number of BOM items quickly and efficiently. Within the iPPE product structure, the product variant structure is for maintaining configurable materials and the assembly group is for maintaining non-configurable materials without direct reference to the configurable final product.

i. Product Variant Structure (PVS)

The product variant structure (PVS) is particularly suited to products that consist of a large number of individual materials and that are made and configured to order. The PVS objects are part of Integrated Product and Process Engineering (iPPE). They are assigned to the application object type CMP (component) and therefore represent the product structure in iPPE.
19 Fig. 6.12 Structure and Elements of the PVS

The product classes and product class hierarchies to which you assign the nodes are above the PVS. The concrete products and assemblies that are assigned to the component variants are below the PVS, as well as the assemblies that the products consist of.

ii. Assembly group

Assembly group represents non-configurable structures in Integrated Product and Process Engineering (iPPE). It enables us to use iPPE and its functions even when you do not need configuration, or when you create both configurable and non-configurable structures.

The advantage of separating configurable product structures (PVS) and non-configurable product structures (assembly) is that the master data from assemblies can be re-used for different products.

In contrast to the PVS, this object represents a breakdown of the product that is not specific to a product class, and it enables the representation of an assembly structure without
configuration. It helps to avoid multiple documentations by using an assembly to represent frequently occurring assemblies or parts of a bill of material. This is the case for components such as car seats or airbags.

We can store structured documents (assembly documents, for example) in an assembly. Several products with similar or identical breakdowns can be grouped in one variant assembly and we can use the node structure of the variant assembly as a template to simplify the maintenance and creation of new assemblies or the node structure of the variant assembly to check the completeness of new assemblies by comparing the node structures.

**Interaction of PVS and variant Assembly**

Fig. 6.13 Interaction of PVS and Variant Assembly
Breakdowns of a product that are not specific to a product class are documented in an assembly. This is why the assembly or variant assembly has product breakdowns below the PVS only.

There are two types of assemblies as shown in fig. 6.15.

i. Variant Assembly: It is used when breakdowns of certain components are always the same or similar.

ii. Multiple Assembly: It is used to maintain location specific breakdowns of a product.
6.7.2 iPPE Process Structure

iPPE Process Structure represents routing data and it is used to manage production master data. It describes the production process for the in-house manufacturing of products, in the same way as a classical routing. It consists of different node types that represent routing data. The complete iPPE model includes the process structure, the product variant structure (for BOMs), and the factory layout (line design). The functions of the individual applications are linked to each other.

The process structure is particularly suited for planning the workflow on production lines with takts, where the products are always processed in the same manner. The process structure is the basis for line balancing in line design. Line balancing is based on the duration that is defined for the activities in a process structure or the production rate that is defined in the Line layout.
The process structure offers the following advantages over the classical routing:

i. Production process can be modelled on a logical and on a functional level, that is, it is possible to create routing data before the concrete products are created in the system.

ii. Creating just one process structure for all products that are produced with the same production process is enough, even when the products are produced in different plants.

iii. Using one process structure to represent the entire production process for a product, from body-in-white through to final assembly.

The process structure is the basis for line balancing in line design. It is particularly suited for products with many variants.

There are four different node types for maintaining a process structure:

i. Routing header

The routing header node type forms the highest level in the structure. It defines the sequence of the activities that have to take place. This node type corresponds to the routing header in the classical routing.

ii. Activity

The activity is the basic element in a process structure and, together with the mode, describes how a process step is to be executed.

iii. Grouping activity

When certain activities and operations are always executed in the same sequence, it is advisable to use a grouping node to bring together several activities and operations for multiple uses and then one can insert the grouping node into different process structures.

iv. Operation

You can use the operation node type to group activities, but not to represent multi-level structures. However, using an operation node has the advantage that all activities assigned to the operation node are selected for configurable products.
Fig. 6.16 Multi Level Process Structure using the four nodes

Routing Header

Grouping Nodes
- Install Cables
- Install Engine
- Interior Work

Grouping Nodes
- Assemble Dashboard

Operations
- Install Dashboard
- Install Steering Wheel

Activities
- Activity 1
- Activity 2

Fig. 6.17 Multi Level Process Structure in a Car Industry

To carry out Planning processes production resources, which are the bases of product cost planning and for labour resource planning, and activity times (bases of sequencing) must be introduced in the iPPE Process Structure. A production resource can be an individual machine, a production line, a production resource/tool, an employee or group of employees.
The Assignment of activities to the respective components in the product variant structure will show us which component will correspond to which activity.

6.7.3 iPPE Line Design

The iPPE Line Design helps to create the structure and properties of production lines as master data in the system, within iPPE. The iPPE Line Design depicts individual production lines, linear line networks, and highly complex line networks with alternative lines, such as those in the automotive industry, which is the case study is taken from. Moreover, for interlinked assembly lines, we can also carry out a line balance, to determine the optimum work content of the individual line segments. It is suitable for repetitive or flow manufacturing with takts, where the workstations are linked, both in place and time. The system sets the scheduling type to takt based scheduling.

The APO components in the automotive process, model mix planning and rapid planning matrix, use the line structure for logistic and planning functions, such as optimizing the sequence or determining requirement times for the components. The line structure is transferred into the APO together with the process structure and product structure to enable planning in the APO.

The APO uses the line resource for planning. The line resource supports the special type of capacity planning on lines and takt-based scheduling. A line resource is automatically created in the APO for each production line (node type ‘line’) when line structures are transferred into the APO using the APO Core Interface. You define the production rates for takt-based scheduling for each line resource in the APO. The line determines the working time capacity and the production rates and transfers these to the lower-level line segments. The iPPE Line Design enables us to specify the number of takts on the lowest level of the line hierarchies and also insert buffers in-between two lines in the line structure, in which orders can be stored temporarily. We cannot use lead-time scheduling with a routing for line design.

With the line structure one can reproduce the structure of interlinked production lines for takt based flow and repetitive manufacturing in the system. The line structure consists of various line elements with specific functions. These line elements should be arranged in a hierarchy. Fig. 3.17 shows the hierarchical structure of a line structure using the most important node types.
In Production line of an Automotive Industry the arrangement and planning of shops with respect to different classes is one of the basic problem in planning. In APO these problem can be solved by using the different shops as an alternative and entering the possible paths for each product, as shown in Fig. 6.19. By doing these products of different classes can be planned quickly and effectively using one model and produced in existing shops.

Fig. 6.18 Multi Level Production Line structure in a Car Industry
6.8 Line Balancing

A product layout arranges machines or workers in a line according to the operations that need to be performed to assemble a particular product. From this description, it would seem the layout could be determined simply by following the order of assembly as contained in the bill of material for the product. To some extent, this is true. Precedence requirements specifying which operations must precede others, which can be done concurrently and which must wait until later are an important input to the product layout decision. But there are other factors that make the decision more complicated. 20

Product layouts or assembly lines are used for high volume production. To attain the required output rate as efficiently as possible, jobs are broken down into their smallest indivisible portions, called work elements (Takts). Work elements (Takts) are so small that they cannot be performed by more than one worker or at more than one workstation (work Area). But it is common for one worker to perform several work elements as the product passes through his or her workstation. Part of the layout decision is concerned with grouping these work elements into workstations so products flow through the assembly line smoothly. A workstation is any area along the assembly line that requires at least one worker or one machine. If each workstation on the assembly line takes the same amount of time to perform the work elements that have been assigned, then products will move successively from workstation to workstation with no need for a product to wait or a worker to be idle. The process of equalizing the amount of work at each workstation is called line balancing.

20 Demirli, K. & Yimer, A. D., 2008

Fig. 6.19 Line Structure for a Line Network with Alternatives
Assembly line balancing operates under two constraints, precedence requirements and cycle time restrictions.

Precedence requirements are physical restrictions on the order in which operations are performed on the assembly line. For example, we would not ask a worker to package a product before all the components were attached, even if he or she had the time to do so before passing the product to the next worker on the line. To facilitate line balancing, precedence requirements are often expressed in the form of a precedence diagram. The precedence diagram is a network, with work elements represented by circles or nodes and precedence relationships represented by directed line segments connecting the nodes. We will construct a precedence diagram later in example. 21

Cycle time, the other restriction on line balancing, refers to the maximum amount of time the product is allowed to spend at each workstation if the targeted production rate is to be reached. Desired cycle time is calculated by dividing the time available for production by the number of units scheduled to be produced:

\[
C_d = \frac{\text{Production time available}}{\text{Desired units of output}} \quad \text{(6.1)}
\]

Suppose a company wanted to produce 120 units of Car in an eight-hour day. The cycle time necessary to achieve that production quota, is

\[
C_d = \frac{(8 \text{ hours} \times 60 \text{ minutes} / \text{hour})}{120 \text{ Units}}
\]

\[
= \frac{480}{120} = 4 \text{ minutes}
\]

Cycle time can also be viewed as the time between completed items rolling off the assembly line. Consider the three station assembly line shown here.

21 David, 2000, Pages: 52-56
Fig. 6.20 Cycle Time

It takes 12 minutes (i.e., $4 + 4 + 4$) for each item to pass completely through all three stations of the assembly line. The time required to complete an item is referred to as its flow time, or lead time. However, the assembly line does not work on only one item at a time. When fully operational, the line will be processing three items at a time, one at each workstation, in various stages of assembly. Every 4 minutes a new item enters the line at workstation 1, an item is passed from workstation 1 to workstation 2, another item is passed from workstation 2 to workstation 3, and a completed item leaves the assembly line. Thus, a completed item rolls off the assembly line every 4 minutes. This 4-minute interval is the actual cycle time of the line.

The actual cycle time, $C_a$, is the maximum workstation time on the line. It differs from the desired cycle time when the production quota does not match the maximum output attainable by the system. Sometimes the production quota cannot be achieved because the time required for one work element is too large. To correct the situation, the quota can be revised downward or parallel stations can be set up for the bottleneck element.

Line balancing is basically a trial and error process. We group elements into work stations recognizing time and precedence constraints. For simple problems, we can evaluate all feasible groupings of elements. For more complicated problems, we need to know when to stop trying different workstation configurations. The efficiency of the line can provide one type of guideline; the theoretical minimum number of workstations provides another. The formulas for efficiency, $E$, and minimum number of workstations, $N$, are
\[ E = \frac{\sum_{i=1}^{j} t_i}{nC_a} \quad \quad N = \frac{\sum_{i=1}^{j} t_i}{C_d} \quad \quad (6.2) \]

Where

- \( t_i = \) Completion time for element \( i \)
- \( j = \) number of work elements
- \( n = \) actual number of work stations
- \( C_a = \) actual cycle time
- \( C_d = \) desired cycle time

The total idle time of the line, called balance delay, is calculated as (1 - efficiency). Efficiency and balance delay are usually expressed as percentages. In practice, it may be difficult to attain the theoretical number of workstations or 100 percent efficiency. The line balancing process can be summarized as follows:

i. Draw and label a precedence diagram.

ii. Calculate the desired cycle time required for the line.

iii. Calculate the theoretical minimum number of workstations.

iv. Group elements into workstations, recognizing cycle time and precedence constraints.

v. Calculate the efficiency of the line.

vi. Determine if the theoretical minimum number of workstations or an acceptable efficiency level has been reached. If not, go back to step 4.

Even though the main aim of the thesis is on the automotive industry for the sake of line balancing simplicity let us use one case of real fruit snack strips.

Real Fruit Snack Strips are made from a mixture of dried fruit, food coloring, preservatives, and glucose. The mixture is pressed out into a thin sheet, imprinted with various shapes, rolled, and packaged. The precedence and time requirements for each step in the assembly process are given below. To meet demand, Real Fruit needs to produce 6,000 fruit strips every 40-hour week. We want to design an assembly line with the fewest number of workstations that will achieve the production quota without violating precedence constraints.
First, we draw a precedence diagram. Element A has no elements preceding it, so node A can be placed anywhere. Element A precedes element B, so the line segment that begins at node A must end at node B.

### Table 6.21 Data for Line Balancing of real fruit snack strips

<table>
<thead>
<tr>
<th>Work Element</th>
<th>Precedence</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Press out sheet of fruit</td>
<td>---</td>
<td>0.1</td>
</tr>
<tr>
<td>B Cut into Strips</td>
<td>A</td>
<td>0.2</td>
</tr>
<tr>
<td>C Outline fun shapes</td>
<td>A</td>
<td>0.4</td>
</tr>
<tr>
<td>D Roll up and Package</td>
<td>B, C</td>
<td>0.3</td>
</tr>
</tbody>
</table>

28 Table 6.21 Data for Line Balancing of real fruit snack strips

Element A precedes element C. Again, a line segment from node A must end at node C.

29 Fig. 6.22 Precedence diagram of A and B

30 Fig. 6.23 Precedence diagram of A, B and C
Elements B and C precede element D, so the line segments extending from nodes B and C must end at node D. The precedence diagram is completed by adding the time requirements beside each node.

![Precedence Diagram]

31 Fig. 6.24 Precedence diagram of A, B and C

Next, we calculate the desired cycle time and the theoretical minimum number of workstations:

\[
C_d = \frac{40 \text{ hours} \times 60 \text{ minutes/hour}}{6,000 \text{ Units}} = \frac{2,400}{6,000} = 0.4 \text{ minutes}
\]

\[
N = \frac{0.1 + 0.2 + 0.3 + 0.4}{0.4} = \frac{1.0}{0.4} = 2.5 \text{ Stations}
\]

Since we cannot have half a workstation (or any portion of a workstation), we round up to 3 workstations. We must group elements into workstations so that the sum of the element time at each workstation is less than or equal to the desired cycle time of 0.4 minutes.

Examining the precedence diagram let us begin with A since it is the only element that does not have precedence. We assign A to workstation 1. B and C are now available for assignment. Cycle time is exceeded with A and C in the same workstation, so we assign B to workstation 1 and place C in a second workstation. No other element can be added to workstation 2, due to cycle time constraints. That leaves D for assignment to a third workstation. Elements grouped into workstations are circled on the precedence diagram.
Our assembly line consists of three workstations, arranged as follows:

<table>
<thead>
<tr>
<th>Work Station</th>
<th>Element</th>
<th>Remaining Time</th>
<th>Remaining Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>0.3</td>
<td>B, C</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.1</td>
<td>C, D</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>0.0</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>0.1</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 6.25 Data for Line Balancing of real fruit snack strips

Fig. 6.26 Precedence diagram of A, B and C

Since the theoretical minimum number of workstations was three, we know we have balanced the line as efficiently as possible.

Fig. 6.27 Precedence diagram of A, B, C and D
The assembly line has an efficiency of

\[ E = \frac{0.1 + 0.2 + 0.3 + 0.4}{3 \times 0.4} = 0.833 = 83.3\text{Percent} \]

Line balancing by hand becomes unwieldy as the problems grow in size, like in the automotive industry. Fortunately, there are software packages that will balance large lines quickly. Now in this case study we are using SAP APO to balance the lines.

### 6.8.1 Line Balancing in SAP APO

Line balancing reconciles the time capacity and the required time on a production line. Line balancing consists of calculating the takt time for a line and adjusting the activities on the line to the takt time. We assign activities to the line segments in such a way that to enable the activities to be completed within the predetermined takt time. Line balancing gains importance if we produce several products or product variants on a production line at one time (Model Mix Production), which is common in the automotive industry. Hence Line Balancing is highly applicable in Automotive Industries, where a lot of car variants are expected to be produced on the same production line.

For such a model mix production, the activities in the line segments can have a different duration for the individual products. Takt based scheduling does not take into account the execution times, but multiplies the takt times with the number of takts. Therefore you must assign the activities to the line segments or work areas in such a way that the available time is utilized optimally with the average work content, represented by the capacity requirements of the line element. Within a line balance, Production resources are assigned to the line elements. This assignment represents the available capacity at the line elements, as the amount of time available at the line element is calculated from the assigned production resources. It can be adjusted that the available capacity at a line element to suit the work content. For example, we can increase the number of production resources at the affected line segment.

To balance the lines in iPPE we need to specify:

i. line balance rate for one line balance that determines the takt time,
ii. select a model mix, which is used to calculate the weighted duration per activity and
iii. Production rates for line resource in APO.
35 Fig. 6.28 SAP APO Line Balancing result

36 Fig. 6.29 SAP APO Demand Table
7. Model Mix planning
7.1 Introduction

Production and business systems are key building blocks in the structure of modern industrial societies. Different human activities and the prosperity of whole nations are highly dependent on the performance of production and business systems. Companies and industrial firms, through which production and business operations are usually performed, represent the major sector of today’s global economy. Therefore, in the last decade, companies have made the continuous improvement of production and business systems a milestone in their strategic planning for the new millennium. To remain competitive, companies have to maintain a high-level of performance by maintaining high quality, low cost, low manufacturing lead times, and high customer satisfaction. It is usually asserted that production and business operations have the potential to strengthen or weaken a company’s competitive ability. Therefore, and as a result of fierce competition and decreasing business safety margins, efficient and robust production and business operations become a necessity for survival in the marketplace. Because of this, improving the performance of production and business systems has been the primary interest of decision-makers and engineers.

Businesses have inevitable obligation to deal with supply and demand fluctuations, changes in work scope, and trend dynamics of the market. Therefore, lean production and business systems demand continual improvement of delivery times, operating costs, capacities, material utilization, and information flow. Advanced Planning Systems (SAP APO) and the involvement of planning software (DES) have helped companies design and maintain the flexibility of their key production and business operations and, therefore, remain competitive. Adapting to changes in the product-mix is one aspect of this flexibility.

Dynamic changes in demand, supply, and manufacturing strategies force companies to make continuous changes to the product-mix. Making such changes gracefully and effectively can be only accomplished when systems design is based on flexible production and business operations. The issue becomes even more challenging when the frequency of product-mix change increases. Therefore, under such conditions, determining the optimum product-mix and analyzing its implications as an integral part of the design process becomes essential for achieving robust and flexible production and business systems.

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22 J. A. Joines, R. R. Barton, K. Kang, and P. A Fishwick, 2000, Page: 3
7.2 Product Mix Decisions

An organization’s product-mix is the percentage of total output devoted to each product. For example, an agency that sells life, house, and automobile insurance might have a product-mix of 20%, 30%, and 50% for the three services respectively. In production, for example, an automobile manufacturer might have a product-mix of 50%, 25%, and 25% for cars, pick-up trucks, and sport utility vehicles (SUVs). In a single Automotive factory layout determining the product mix of different variants of cars for example, 25% Variant 1, 25% Variant 2, 16.7% Variant 3, 16.7% Percent variant 4 & 16.7% Variant 5 and determining the sequence needs a through investigation and analysis. For the Product mix analysis focuses on determining the optimum product mix and highlights the implications of varying the percentage of each product on different production and business activities.

Since different products/Variants have different production rates, the capacity requirements for each mix of products may, in some cases, drastically change. For example, increasing the proportion of a certain product in a production schedule may require duplicating a certain machine tool to cope with the rate of production, which may eventually lead to adding a parallel processing line and a new line of products to make use of the added capacity. Therefore, product-mix analysis aims at answering the question: How does product-mix changes affect system capacity? System capacity can be defined in terms of buffer sizes and manufacturing resources types, set-up, utilization, and availability.23

Product-mix decisions are usually influenced by the product selection decision. When a firm has a current market for two or more products, a decision is usually taken to introduce more than one product to the market in an effort to increase market share and profitability. Specially this is common in Automotive Industries, where many variants are produced according to customer order. For example BMW offers up to 1032 variants (at least theoretically), several thousands of them actually are being demanded. Deciding to produce more than one product type or to provide more than one service leads to the issue of product-mix selection. Product selection decision is usually based on the organization goals, environment, and the organization’s production, marketing, and financing strategies.

Once product types are selected, decisions must again be made within each product line with respect to which mix of products to produce and which production processes to use in view of cost, capacity, and the theory of constraints. Product-mix decisions are typically dependent on market research and marketing strategies. Therefore, the product-mix in a production plan

23 Raid Al-Aomar, 2000, Page: 3
is not usually fixed. The mix may change dynamically at different time periods. Figure 1 shows examples of product-mix changes in different time periods of an automotive industry with four variants.

As the frequency of product-mix changes increase, the flexibility in the structure of the organization and production system should be also increased in order to adapt with these changes without impacting business targets and customer satisfaction.

37 Fig. 7.1. Example of product mix of an automotive industry with five car variants

With product mix dynamic changes

As the frequency of product-mix changes increase, the flexibility in the structure of the organization and production system should be also increased in order to adapt with these changes without impacting business targets and customer satisfaction.

24 Raid Al-Aomar, 2002, Pages: 3-5
7.3 Product Mix Determination

For some firms, determining the product-mix is one of the most important decisions relating to production planning. Such decision implies utilizing limited resources to maximize the net value of the output from the production facilities. The quantity produced from each product in a certain time period results in utilizing certain resources for that time, consuming certain amount of raw materials, using certain labour skills and various production centers, and so on.

The general objective of the product-mix decision in the overall production plan is to find the product mix and the production program that maximizes the total contribution to profit/throughput subject to constraints imposed by resource limitations, market demand, and sales forecast but in some cases if different objectives arise we have to follow some steps to determine the correct product mix to achieve the desired target.

In automotive industry a company produces so many product variants and determining the product mix is a big problem. Each product requires certain amount of labour and materials, Constraints, such as total amount of resources and the maximum number of units that each product can sell, as well as the unit profit for each product, are given. The analysis focuses on how many products to produce in order to maximize the overall profit, correctly illustrating the essence of the product mix problem.

First, the data needed for product mix study must be organized in handable format so that the Operations research practitioner can use them directly for analysis. After the first hurdle in data requirements is crossed and initial analysis of the product mix is conducted, a practitioner will usually be faced with the next issue: Is the current "optimized" product mix truly the best? In practical applications, the product mix study is rarely a one-shot deal, taking time and effort. Analysis is iterative, each iteration representing one of numerous different business and/or production scenarios.25

The third difficulty of product mix analysis is its implementation. Even after an "optimal" product mix is found, the realization of the product mix within the operation is a challenge. An optimized product mix usually represents an idealized and somewhat macro view of the production profile, delivering a profit obtained in the analysis. In many cases, however,

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25 Raid Al-Aomar, 2002, Pages: 3-5
operational constraints in production and in the supply chain that were not or cannot be specifically formulated into the product mix optimization such as availability of raw materials, seasonality of customer demand and bottlenecks of equipment and resources may deem your product mix results infeasible. Therefore to escape the above stated problems the following steps are suggested to improve the success rate of a product mix study.

**Step 1: Defining the product mix problem**

The purpose of a product mix study for a profit making entity is usually to maximize the profit. Assuming this general principle, one needs first to define and understand the project. The following questions clearly identify the problem/opportunity and provide focus to the project.

i. What is the objective of this product mix study project?
ii. What are the issues involved with this project?
iii. Why is it important?
iv. Who is the sponsor for this project?
v. Who should be working on this project?
vi. When should the project start? Finish?
vii. What is the current product mix?
viii. What is the current profit picture?

By answering the above questions, one can achieve a much better understanding of the issues involved and point the project in the right direction toward a successful analysis.

**Step2: Collecting data for base-line product mix evaluation**

The most important decision of this step is to define the product categories to use as the basic unit to collect needed information. A typical company sells hundreds or even thousands of products representing various product lines, product classes, product sub-classes, packing codes, etc. It is extremely cumbersome and difficult to conduct product mix analysis at the lowest product classification level with thousands of categories. Aggregation is always needed. The question is therefore how to aggregate product sub-classes such that the analysis will still yield insightful outputs. 26

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26 Thomas, 1998, Pages: 8-11
This is a very time consuming period of the project. In the case of an entity with a good database containing accurate financial and operation information, effort is usually spent on the aggregation of information to arrive at the desired product category level. To alleviate any ambiguity during the data collection and aggregation process, design a spreadsheet, clearly listing product categories and information to be collected first. With a clear list of information needs, the goal of the data collection is simply to complete the spreadsheet that was specifically designed for data collection.

Typical information to be collected for product mix analysis will include items such as product price, product costs (fixed, variable and overheads) and estimated demand for the product at the planned horizon. The sales and marketing group will provide two numbers for the estimated demand: one number for the expected demand and the other for a higher estimated demand if the product is pushed given a price reduction. Processing information for each product such as equipment usage requirements for key equipment and resources must also be collected. Detailed processing information for all equipment is not really necessary. Identify the key constraints in the production process first, and then collect equipment usage requirements for the potentially constrained equipment only. With all the needed information collected in a spreadsheet, formulating the product mix question using the spreadsheet solver will proceed. 27

**Step 3: Developing new scenarios for additional product mix analyses**

The "optimized" product mix output from Step 2 is the current best under a limited scope no changes are made to the currently available equipment and resources. The real challenge of a product mix analysis is to create new business and production scenarios that frequently require major "structural" changes. The structural changes might involve the bold "re-engineering" of the business; for example, shutting down some portion of the operation thereby eliminating some product lines, or adding some product lines by realigning existing equipment/resources among several production sites or acquiring new equipment/resources etc. The principle concept behind the scenario development is to come up with a viable and feasible business plan and structure that will improve the bottom line. The scenario development is by far the most challenging part of a product mix study because it involves

27 Raid Al-Aomar, 2002, Pages: 1-3
business strategy, breaking the existing product mix paradigm and invoking "outside-the-box" thinking to brainstorm good scenarios for the business to pursue.

For each scenario, appropriate data will of course need to be added and incorporated into the existing data structure discussed in Step 2. Product mix analysis will need to be conducted for each scenario. Results will need to be evaluated for assessing the viability of the scenario. Frequently, the result of one analysis will direct the development of a new scenario for further analysis. In fact, product mix analysis is likely to be iterative in practical applications.

If structural changes suggest acquisition, the same product mix analysis must be conducted assuming the acquisition has taken place. The merit of this possible acquisition can be assessed from the analyses by comparing product mix results with and without acquisition.

**Step 4: Selecting an optimal product mix profile**

Since the product mix analysis involves entertaining multiple scenarios and the process of searching for the best scenario, the process is usually iterative. So in actual practice, Step 3 and Step 4 are closely linked. In this step, the following questions help the selection process:

1. Does the solution (i.e., the proposed product mix profile and the resultant profit estimate) meet the objective of the project?
2. What criteria are used for comparing various proposals and solutions?
3. In what ways are some product mix scenarios more desirable than others?
4. What are the pros and cons of each product mix scenario? How do the possible solutions relate to the original intent of the project?
5. What is the best solution?
6. Can we try out the possible solution on a small scale? (If piloting is possible, what data will we collect?)

Answering the above questions helps me to be objective in selecting the best product mix scenario and production profile.
Step 5: Mapping out the actual production sequence to verify the feasibility of the optimal production profile.

The optimal product mix profile obtained in Step 4 may not necessarily be feasible to execute on the production floor. The reason is simple. The product mix analysis is usually conducted at a macro level where only major constraints are considered in the optimization formulation. Additionally, some of the constraints on the production floor cannot easily or even possibly be handled by a mathematical programming formulation. As a result, the "optimal" product mix profile obtained in Step 4 is in fact an upper bound. Actual profit figures may be lower due to additional practical constraints that fail to be included in product mix optimization formulation.

To overcome this possible gap, it is necessary to map out the production runs using the optimal product mix profile and to verify production feasibility. There are, of course, many ways to accomplish this task. Some people use simulation while other people prefer traditional paper and pencil to test the actual production schedule. It is best to have an optimal scheduling system and a specialized equipment utilization chart to schedule production sequences and to map out the detailed production run — hour-by-hour equipment utilization for the total duration of a production sequence. A typical output of this type of equipment utilization chart is shown in Figure 2. The scheduling and equipment utilization chart outputs provide us the necessary verification that the optimal product mix profile as obtained in Step 3 and Step 4 is feasible. These steps are designed to actualise a real product mix project.

i. Product mix should be updated regularly as demand, prices, costs and structure change. Therefore, Steps 3 through 5 have to be repeated when input data changes.

ii. Product mix analysis can play a central role in the annual strategic and business planning process. It provides credence and objectivity to an otherwise qualitative-natured strategic planning process. Also, product mix analysis can provide insight for major restructuring or acquisition considerations.

iii. On the surface, product mix analysis is simple. Because of this apparent simplicity, it is extremely easy to fall into the pit of knowing enough to be dangerous but not enough to carry out a thorough study. The suggested five-step roadmap was developed and refined through years of applications.
iv. It is easy to fall into the trap of something I call "product mix paradigm." People tend to be comfortable in status quo and prefer to be in the same position, producing the same products forever. The competition and market change more rapidly now than ever. It is imperative to allow the customer needs to drive the product mix rather than the limitations of the producer. In fact, many company failures are caused by this paradigm: an unwillingness to switch the product mix from a producer's orientation to a customer's orientation.

As discussed in Step iii, developing new scenarios for product mix analysis is a real challenge. The key element of success for this step is to have a group of people knowledgeable about the operation and the business to generate meaningful scenarios and to have relevant data available for rapid product mix analysis.

### 7.3.1 Product Mix calculation

The aim of the product mix calculation depends on the company’s product mix definition but mostly it is to determine most profitable mix over planning horizon subject to certain constraints. Some of the inputs for the product mix calculation are demand forecast by product (family?); may be ranges, unit hour data, capacity constraints, unit profit by product, holding cost, basic Verbal Formulation.

Maximize: \[ \text{profit} \]

Subject to: \[
\begin{align*}
\text{Production} & \leq \text{capacity, at all workstations in all periods} \\
\text{Sales} & \leq \text{demand, for all products in all periods}
\end{align*}
\]

Product Mix Notation
There are two approaches to solve this task.  

1. **A Cost Approach:** This method takes only the profit in to account by taking weekly, monthly or yearly planning periods.

2. **A Bottleneck Approach:** This method takes the bottleneck resource or assembly station as a basis of calculation.

The output of the product mix profile is best presented in a graphical format. Outputs of this step will usually include at least two parts:

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28 Thomas, 1998, Page: 15
1. The existing product mix, and

2. The "optimized" product mix, both of which are derived from the currently available equipment/resources and existing processes.

These are the data used as an input for the SAP APO Model Mix Planning Module to determine the assembly sequencing by taking the iPPE structure and the customer order into consideration.

The product mix analysis is not included in the SAP APO Repetitive Manufacturing Module. Hence, one must calculate the product mix percentage before he/she began to solve the planning task using SAP APO. The system doesn’t calculate the model mix percentage even though the sales data and other business aims are already fed. The model mix percentage should be determined by a separate software (usually excel sheet) developed by the specific company by taking the sales and other important data into consideration as stated above.

**7.4 Model Mix Planning module in SAP APO and Takt Based Scheduling**

Takts are the smallest units of a production line. They are the physical areas that the material passes through in the predefined takt time, where it is processed. The lengths of the production line are defined by the amount of takts. Alongside the rates (takt times), the
number of takts that a material has to pass through is a further parameter for takt based scheduling.

In takt-based scheduling, the system multiplies the number of takts with the takt time. This means that by determining the number of takts one also determines the capacity of a line segment. If you subdivide a line segment into work areas, they are scheduled in the same way as the higher-level line segment.

The following example shows seven line segments that are arranged in sequence and in parallel using sequence relationships. For takt-based scheduling, the system determines the longest path through this network. This goes through line segments 1, 4, 5, 6 and 7 and is 20 takts long. The system copies these 20 takts into the number of takts field of the higher-level line segment.

![Diagram of line segments with takt times](image)

**Longest path = 20 Takts**

39 Fig. 7.3 Determination of the Longest Path

Takt based scheduling is used especially for production lines. In takt-based scheduling, APO calculates the lead time of an order not from the duration of the activities, but by multiplying the number of takts with the takt time. The takt time is therefore the reciprocal of the rate. This type of scheduling allows scheduling a large order volume, as APO does not have to calculate the durations from the routing, but only creates the capacity requirements for the line resource.

In flow and repetitive manufacturing, the materials remain for the defined takt time in a takt of the line, to be processed. The execution times that are calculated from the routing may vary from this takt time. Therefore takt-based scheduling produces a more exact result for takt-based flow manufacturing, then lead time scheduling (fig. 7.3).

The number of takts (processing stations) that a material has to pass on the production line are calculated from the longest (critical) path through the line structure, which are created for
linear line networks. For line networks with groups of alternative lines, it uses the parts of line networks to calculate the processing path for the product being planned. The base rate and the production rate valid on the key date, whose reciprocal values determine the takt times. The product-dependent rates that the system saves as a factor relative to the base rate. Takt-based scheduling multiplies this factor with the valid production rate of the period and in this way controls the production rate in scheduling.

In takt based scheduling the system multiplies the number of takts of the longest path through the line, or the selected processing path, by the takt time. The takt time results from the production rate, if you have entered a valid production rate for the current period. Otherwise the system uses the base rate of the line. Note that the rate of resource utilization, which you can enter in the line resource, has a similar effect to the production rate. The system uses the production rate to determine a factor relative to the base rate, which it multiplies with the base rate in scheduling. The rate of resource utilization has exactly the same function. If you enter a production rate and also change the rate of resource utilization of the line, both these parameters have a multiplying effect.

If the base rate is 100pc/hr, the production rate is 80pc/hr, and the performance level is 80%, the system schedules with 64 pc/hr. The following figure shows how lead time scheduling would produce a false result. Takt-based scheduling, on the other hand, which multiplies the takt time with the number of takts, produces a correct result.
There are two forms of Takt based Scheduling systems.

i. Rate dependant takt time scheduling system
ii. Rate independant takt time scheduling system

**7.4.1. Rate-Dependent Takt Time Scheduling System**

This method is used to balance a change in production volume with a change in the speed of your production line. This means that not just putting on less or more products per time unit on the production line, but also change the speed of the line. In other words it means the time available for processing a product depends on the current valid production rate.

Rate-dependent takt based scheduling is the form of takt based scheduling that is used the most in practice. We use takt-based scheduling with a rate-dependent takt time for model mix planning and for the takt-based scheduling that you can access from the product planning table.\(^29\)

In takt-based scheduling the system multiplies the takt time with the number of takts in the longest path through the line. If a valid production rate exists at the time of scheduling, the reciprocal of this rate determines the takt time. This takt time determines in which time

\(^29\) APO online documentation, 2010
intervals a product enters the line and leaves it again. In addition, it determines the time available in a takt of the line for processing the product.

If we have not entered a valid production rate for the current period, the system uses the base rate of the line instead. We should therefore create the base rate as the standard rate for a normal operating level and then define a production rate for seasonal fluctuations, for example Takt-based scheduling with a rate-dependent takt time can be clarified with this formula:

\[
\text{Lead time} = (\text{Number of taks} - 1) \times \frac{1}{\text{Production rate}} + \text{Order quantity} \times \frac{1}{\text{Production rate}} \quad (7.2)
\]

This formula is simplified. In takt-based scheduling the system also considers breaks and waiting times that could result in a buffer, for example the following figure shows a simple example for takt-based scheduling with a rate-dependent takt time. The line has a total of 3 takts and the production rate is 6 pieces per hour. The reciprocal of the production rate results in a takt time of 10 minutes. In this case the base rate is not considered.

![Fig. 7.5 Rate dependant takt based Scheduling](image-url)
7.4.2 Rate-Independent Takt Time Scheduling System

This method is used to settle operating differences not with a change in the line speed, but just by changing the speed of entry to the line. This means that you operate the production line with a constant speed and the time available in a takt is not dependent on the current valid production rate. You do not put a material on the line in every takt, but on every other takt, for example. In this way you reduce the quantity performance of the line per time unit.30

The rate-independent takt time cannot be used for model mix planning. In takt-based scheduling with a rate-independent takt time, the system uses two different takt times that result from the reciprocals of the base rate and the production rate:

i. The reciprocal of the base rate defines how long a product remains in a takt for processing. As the base rate is not time-dependent, the speed of the line is always constant.

ii. The reciprocal of the production rate determines which quantities are produced per time unit in a specific period. The production rate determines in which time intervals a product enters the line and leaves it again.

If a valid production rate does not exist at the time of scheduling, the reciprocal of the base rate determines both takt times. Takt-based scheduling with a rate-dependent takt time can be clarified using the following formula:

\[
\text{Lead\_time} = (\text{Number\_of\_takts} - 1) \times \frac{1}{\text{Base\_rate}} + \frac{1}{\text{Order\_quantity} \times \text{Production\_rate}}.
\]

(7.3)

This formula is simplified and does not include, for example, any breaks or waiting times that can result in a buffer. As in this procedure of takt-based scheduling, a material is not put in every takt, theoretically gaps can occur between two orders, where the line is not occupied with an order. However, the system calculates these gaps in the following order, as the order can also be already processed in this time.

The following example shows takt-based scheduling with a rate-independent takt time. The production rate is only half as high as the base rate. Therefore a material is only put onto every second takt and the lead time of the order is 60 minutes. The first piece of the order

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30 APO online documentation, 2010
remains in the first takt of the line for two takt times, because when scheduling, the gap between two orders is used from the following order.

![Diagram of takt-based scheduling](image)

**Fig. 7.6 Rate independent takt based Scheduling**

This component of SAP APO is used for takt-based, flow manufacturing for configured products with a high volume of orders, such as cars with different variants and some components of cars like engines, for example. In this type of production, different products are often produced together on one production line or a line network.

The aim of Model Mix Planning is to create a production schedule in the medium to long term planning horizon. Various heuristic procedures are available for dispatching the orders. When planning, the system has to take the delivery dates, available capacities and any existing restrictions into account. The system creates Period Packages, which are assigned to the lines on which they are to be processed.

In the short-term planning period, the system uses these period packages to calculate an order sequence with exact start and end times, which it does in Sequencing. This order sequence takes restrictions and customer required dates into account and fulfills certain business aims which may include the following, for example:

i. an equal load of the line segments or taks
dii. a minimization of restriction violations
diii. a minimization of the absolute schedule deviation

We can execute Model Mix Planning to plan individual lines or for a complete line network. The line network may exist as a series of lines one after the other or also as parallel lines,
which may be used as alternatives. In this case, Model Mix Planning is executed as planning. The following graphic (Fig. 7.7) shows the creation of period packages for a line network with alternative lines using multiline planning. The orders are assigned to the possible processing paths taking the predefined restrictions into account:

Model Mix Planning has been developed to cater for the demands posed by large order volumes, such as those in the automotive industry. It enables to plan several thousand orders in only a few minutes based on the master data of the integrated Product and Process Engineering (iPPE). Model Mix Planning uses the Optimization component. The data relevant for planning is transferred to be optimized. The optimization uses the optimization procedures defined in the procedure package to determine the best solution and transfers the results back to Model Mix Planning. Model Mix Planning carries out takt-based scheduling based on iPPE Line Design and the line resources.

The planning of the components required for the orders is integrated in the planning run of Model Mix Planning. Depending on the setting in the product master of the product to be planned, APO calculates the required components either using the rapid planning or by an individual explosion of the iPPE. Model Mix Planning also uses restrictions (such as: restrictions for characteristic values, combinations of characteristic values, for product
numbers as well as for fields in the product master, the availability of machines, work or materials) when planning the order sequence, which means we can define conditions for sequencing. Therefore, restrictions are planning master data:

**Fig. 7.8 Maintaining Restrictions in SAP APO**

The restriction hits view allows a restriction specific evaluation of the results of the model mix planning and sequencing. When displaying the restriction hits in the product planning table, differences can occur in the display between the minimum/maximum allowed quantities and the data in the sequencing. These differences arise, as contrasting methods are used to round the calculation results: In model mix planning, the maximum allowed quantities are rounded down as standard, as the quantities specified in a restriction are not allowed to be exceeded.
7.4.3 Mid Point Scheduling

To determine and calculate the available capacity of a line, the system reads the line resource data relevant to scheduling. For periods planned with period-based procedures, the system calculates a capacity split for each period. For periods planned with sequence-based procedures, the system calculates a takt split for each period. Using this takt split, the system calculates the maximum number of products which can be produced on the line per shift or per day.

As a Prerequisite we have to maintain the line resource data relevant to scheduling. If planning uses a period-based procedure and is to create either shift or daily packages, it is not necessary to calculate an exact takt split as all orders are dispatched to the start of the shift or day. Therefore, the system only determines a simple capacity split with the net operating time of the line resource according to the following formula:

\[
\text{Available capacity} = (\text{gross time} - \text{breaks}) \times \text{rate of resource utilization} / \text{rate} \quad (7.4)
\]

To create a Takt Split if planning uses a sequence-based procedure and is to dispatch orders with lot size 1, the system has to determine an exact takt split to be able to calculate the exact start time for each order.

In this example we will see how the SAP APO mid point scheduling works. The shift starts at 8.00 a.m. and ends at 5.00 p.m. The time from 12.00 p.m. to 1.00 p.m. is defined as a fixed break in the capacity variant. This means the operating time is 8 hours. With a takt time of 1 hour, this results in a maximum production quantity of 8 pieces.

![Fig. 7.9 Shift time distribution](image)

However, we can also define variable breaks in the capacity profile in the Break Duration field. If we define breaks using this option, the break duration is not calculated. Instead, the system increases the takt time. In the following example, the same shift is used as above.
(from 8.00 a.m. to 5.00 p.m.). A break duration of one hour is also recorded in the capacity profile. The takt time is one hour. The line works 8 hours and can therefore produce 8 pieces.

In this case, Model Mix Planning uses an operating time of 9 hours as the break is not taken into account. As a result, the takt time is increased to one hour and 7.5 minutes (9 hours / 8 pieces). This results in the following takt split. The individual times indicate when a piece is placed on the line.

![Takt split diagram](image)

46 Fig. 7.10 Takt split

Using a rate of resource utilization or a shift factor increases or decreases the available operating time. For example, if a line in a shift works 8 hours without a break and you have defined a rate of resource utilization of 110%, the operating time is increased to 8.8 hours.

For the activities APO proceeds as follows when determining the takt split:

i. Determining the operating time: First, the APO determines whether to use the data from the capacity profile, the active capacity variant or the standard available capacity. APO then calculates the working time of the line using the available capacity.

ii. Determining the valid rate: In the next step, APO checks whether a rate model with a valid production rate exists in the active capacity variant. If we have defined a production rate it is used to calculate the takt time. If we have not defined a production rate, the system uses the base rate we maintained in the Standard Capacity tab page.

iii. Calculating the available capacity: APO uses the rate to calculate how many pieces can be produced on the line in the available operating time. This quantity is the available capacity of the line.

Early shift: 6.00 a.m. to 2.00 p.m.

Fixed break: 12.00 p.m. to 1.00 p.m.

Rate of resource utilization in both shifts: 100%
Base rate = 3 pc per hour

Takt time = 20 mins

APO uses this data to calculate the following takt split: Each time indicates when a piece is placed on the line.

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.00 a.m.</td>
<td></td>
</tr>
<tr>
<td>6.20</td>
<td></td>
</tr>
<tr>
<td>6.40</td>
<td></td>
</tr>
<tr>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>7.40</td>
<td></td>
</tr>
<tr>
<td>11.40</td>
<td>Break</td>
</tr>
<tr>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>13.00</td>
<td></td>
</tr>
<tr>
<td>13.20</td>
<td></td>
</tr>
<tr>
<td>13.40</td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3. Tat split table

The available capacity is calculated as follows:

Available capacity in the early shift = 6 x 3 pieces (a.m.) + 1 x 3 pieces (after the break)

= 21 pieces

Mid Point Scheduling process describes how scheduling is executed for Model Mix Planning. Takt-based scheduling is executed in the form of a midpoint scheduling. Midpoint scheduling means that the system always calculates the exact start and finish times for the planning segment only. For the lines before or after the planning segment, the system uses either forward or backward scheduling to calculate the start and finish times of the order activities.

Disadvantages of midpoint scheduling is it may result in too many restriction hits (orders which apply to the object dependency defined in the restriction) within a period on a line or on a group of alternative lines which does not belong to the planning segment.

An even capacity load of 100% cannot be guaranteed within a period for lines that are not the planning segment. However, on average, the load over neighboring periods is usually correct again. The optimization using the LP procedure provides an optimum distribution of orders with restriction hits and, if desired, loads the periods to 100% capacity. However, the results cannot be represented accordingly in planning. Therefore, the disadvantages mentioned above.

From 6.00 a.m. to 8.00 a.m. one piece is placed on the line every 0.6 mins. Between 7.00 a.m. and 9.00 a.m., an assembly is completed every 0.6 mins and leaves the line. The system displays 6.00 a.m. as the start time of the order activity. 8.00 a.m. is displayed as the end time of the activity.
The system then calculates the start time of the planned orders on the following line resource using the following formula:

Start time of order activity 2 = start time of order activity 1 + lead time on line resource 1

End time of order activity 2 = start time + duration of order activity 2

Duration of order activity 2 = order quantity X takt time of line resource 2

The system then calculates the start and end times for order activity 3 on the third line resource the same way. Finally, the system calculates the start and end times of the planned orders using the start time of order activity 1 and the end time of order activity 3.

If in a line network, the second line works faster (higher rate) than the first, the system uses other formulas than the ones specified above. Otherwise, activity 2 would seem to be completed before activity 1 which is not the case. The end time of activity 2 is calculated using the following formula:

End time of order activity 2 = end time of order activity 1 + lead time on line resource 2 + Average retention period in the buffer

Start time of order activity 2 = end time of order activity 2 – duration of order activity 2

Here, scheduling is determined by the underlying start-start and end-end relationship of the two order activities – that is, activity 2 cannot start until the first part has passed through line 1 and, if necessary, the buffer. This procedure is clarified in the following graphic:
A line network consists of three consecutive lines. The first line is defined as the planning segment.

**Fig. 7.12** Figure of activity time calculation

49 Fig. 7.12 Figure of activity time calculation

50 Fig. 7.13 Figure shows planning segment
Line/Line Resource Data

Operation time = 8 hours/shift (no downtime for breaks)
Base rate = 1 piece/hour (takt time = 1 hr)
This means that the available capacity is 8 pieces per shift.

Early shift from 6.00 a.m. to 2.00 p.m.
Late shift from 2.00 p.m. to 10.00 p.m.
Line 1: 4 takts and a buffer with an average retention period of 1 hour.
Line 2: 3 takts and a buffer with an average retention period of 2 hours.
Line 3: 4 takts

Order Data

Planned order 1: 1 piece    Planned order 2: 4 pieces    Planned order 3: 3 pieces

Formulas

Duration of an order activity on a line = order quantity x takt time
End time of an order activity = start time + duration of the order activity
Runtime per piece on a line = number of takts x takt time
+ average retention period in the buffer.

Scheduling results for the three lines is shown as follows.
51 Fig. 7.14 Scheduling line resource 1

<table>
<thead>
<tr>
<th>Line resource 1</th>
<th>Planned order 1</th>
<th>Planned order 2</th>
<th>Planned order 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time</td>
<td>6.00 a.m.</td>
<td>6.00 a.m.</td>
<td>6.00 a.m.</td>
</tr>
<tr>
<td>End time</td>
<td>7.00 a.m.</td>
<td>10.00 a.m.</td>
<td>9.00 a.m.</td>
</tr>
<tr>
<td>Lead time per piece</td>
<td>5 hours</td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
</tbody>
</table>

52 Fig. 7.15 Scheduling line resource 2

<table>
<thead>
<tr>
<th>Line resource 2</th>
<th>Planned order 1</th>
<th>Planned order 2</th>
<th>Planned order 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time</td>
<td>11.00 a.m.</td>
<td>11.00 a.m.</td>
<td>11.00 a.m.</td>
</tr>
<tr>
<td>End time</td>
<td>12.00 p.m.</td>
<td>3.00 p.m.</td>
<td>2.00 p.m.</td>
</tr>
<tr>
<td>Lead time per piece</td>
<td>5 hours</td>
<td>5 hours</td>
<td>5 hours</td>
</tr>
</tbody>
</table>
53 Fig. 7.16 Scheduling line resource 3

<table>
<thead>
<tr>
<th>Line resource 2</th>
<th>Planned order 1</th>
<th>Planned order 2</th>
<th>Planned order 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time</td>
<td>4.00 p.m.</td>
<td>4.00 p.m.</td>
<td>4.00 p.m.</td>
</tr>
<tr>
<td>End time</td>
<td>5.00 p.m.</td>
<td>8.00 p.m.</td>
<td>7.00 p.m.</td>
</tr>
<tr>
<td>Lead time per piece</td>
<td>4 hours</td>
<td>4 hours</td>
<td>4 hours</td>
</tr>
</tbody>
</table>
8. Sequencing
8.1 Introduction on sequencing

The automobile industry is one of the leading industries with a large supply chain. The factory consists of wide variety of manufacturing activities in different shops. Some of the activities are casting, stamping, part manufacturing, welding, painting and assembly. The activities vary from shop to shop or from department to department. The major departments of an Automotive assembly plant include Metal Shop (Body Shop), Body Shop, Painting Shop and Final Assembly Shop. The final assembly shop usually consists of several subassembly lines for items such as engine, frame and instrument panel, and a main assembly line for trim and finish assembly.

As I have tried to discuss in chapter 7, Model Mix Planning is commonly used in an automobile manufacturing. It enables us to gain benefits by maximizing the capability of the lines. It has the benefit of reducing facility and inventory costs, and a potential of achieving a better balance in workload and part usage. When mixed model assembly is applied in an automobile assembly plant, a linear flow can pass through the whole assembly system, and the model sequence can thus affect the production efficiency of various departments. This will enable the production lines to work smoothly at a constant rate (takt based scheduling).

The production considerations for different departments are different, because of the specific requirements and aims to be achieved by respective departments. Hence, production considerations for the efficiency of various departments are generally different. For example, the body shop department may need to follow a repetitive pattern of model due to the machine set up consideration, while the painting department may need to have larger paint colour blocks.

The sequencing procedures can be viewed in two ways, one from the departments view and the other is from the inter departments view. Hence considerations for sequencing may vary from the point of view we are addressing the problem. In this thesis we will see sequencing within final assembly shop with a case study by taking various departmental considerations and sequencing within departments theoretically.
The Final Assembly shop consists of many assembly lines and levelling of work loads gets difficult as the number of lines and car varieties increase. Hence we need various sequencing procedures aimed at levelling work loads on the stations, smoothing part usage on the line or minimizing the variation of production rates of the finished products for a mixed model assembly line.

8.2 Sequence variation in the final assembly plant

The sequence of the linear flow of models on a mixed model assembly can often be varied intentionally or unintentionally in an automobile assembly plant. In some cases, the sequence can be varied intentionally to achieve a better efficiency in a downstream department such as having larger paint blocks for the painting department.

When the initial model sequence is intentionally or unintentionally before reaching the final assembly department, it becomes difficult for the final assembly department to anticipate the exact sequence. At the final assembly department, where a significant number of parts are used, both operators and suppliers can benefit from knowing the model sequence in advance. One important reason for needing to know the sequence in advance is due to the manufacturer’s desire to have parts delivered to the final assembly line according to the sequence. Sequenced parts delivery has become increasingly popular practice in automotive assembly operations. By sequenced parts delivery, parts needed at many assembly stations on the line can be organized and delivered according to the mixed model sequence. The benefits of this practice include reduced inventory level, reduced space requirement, and ease of material retrieval for assembly operations.

Different departments usually do not share one optimal sequence on a moving assembly line, which raises the need to resequence jobs up on leaving a department and before entering the next one. They developed an integrated model to solve the resequencing problem for the downstream department with the objective of minimizing change over costs incurred whenever two consecutive jobs do not have the same feature such as vehicle colour. Limited offline buffers, or pull-off tables were suggested for the proposed vehicle resequencing operation. This problem is not addressed in this thesis with a case study. If we want to deal this problem in SAP APO we have to produce a period package for the whole departments after developing master data for respective departments and restrictions should be created from the specific department requirement and from the interdepartmental perspective also. More over, buffers and some other additional balancing methods should be developed.
8.3 Assembly Line Sequencing

A number of cars are to be produced are not identical, because different options are available as variants on the basic model. Cars in production are placed on an assembly line moving through various units that install options such as air conditioning and radios. The assembly line can thus be viewed as composed of slots and each car must be allocated to a single slot. The assembly line has different stations, which install the various options (air-conditioning, sun-roof, etc.). These stations have been designed to handle at most a certain percentage of the cars passing along the assembly line.

Furthermore, the cars requiring a certain option must not be bunched together, otherwise the station will not be able to cope. Consequently, the cars must be arranged in a sequence so that the capacity of each station is never exceeded. For instance, if a particular station can only cope with at most half of the cars passing along the line, the sequence must be built so that at most 1 car in any 2 requires that option.

Trends in assembly line manufacturing shows the goal of assembly sequencing is to deliver precisely the car that a customer wants, as and when he wants it and it can be termed as goodbye inventory, hello mass customization. To meet the challenges of this intensely competitive environment, automotive companies are

i. Providing greater choice of models, colours and options.

ii. Reducing the order to delivery lead time.

Both trends have a significant impact on the sequencing and scheduling of assembly lines:

i. The complexity of the scheduling problem is greatly increased as more features and options are added.

ii. Order to delivery lead time reduction will require quicker, more accurate and more frequent scheduling since the scheduling process itself is a major component of the lead time.

What is assembly line sequencing and scheduling and why is it important? Assembly line sequencing is the process of assigning a manufacturing slot to each unit or vehicle. The schedule for each unit is established by applying the line speed and build rate to the sequence.
The schedule specifies when each unit is expected to enter (the line on) and leave (the line off) the line.

An automotive top level assembly line schedule is the input for scheduling and execution through the supply chain, which can be several levels deep. For example: Engine groom line, Feeder line, Engine assembly line, Tier 1, supplier, Engine blocks, crankshafts, tier 2 supplier.

Assembly line sequencing is a key element in the order to delivery cycle. Many important processes are dependant on the assembly line schedule, like Customer Relationship Management, Customer order fulfilment, Material planning, Scheduling of feeder lines and Vendor supply chain management. Hence, the sequencing process can directly influence the cost and time required to deliver an order. An effective assembly line sequencing system provides a competitive advantage to an automotive company.

8.4 Sequence Scheduling with APO

The sequence schedule represents the sequence of the APO planned orders for a planning version and a line structure, in tabular form. It provides information on all detailed data, such as the start and end times or the characteristics evaluation.

In addition, you can check the quality of the sequence by displaying the restriction violations. Then you can move the orders manually, or carry out an individual procedure. The data relevant for planning is imported each time the sequence schedule is accessed, so that it always displays the current data. However, we can only move to the change mode if all orders have order quantity 1 and are scheduled in takts. If this is not the case, we can split the orders into a lot size of 1 using takt-based scheduling. We do this in sequencing. The following figures show the sequencing results.
54 Fig. 8.1 Assembly sequencing (Before takt based scheduling)

55 Fig. 8.2 Assembly Sequencing of (after takt based scheduling, with lots size one)
9. Summary

In this summary section we will go step by step through all the questions raised at the beginning of the thesis.

1. What are the trends in Automotive Industry regarding supply chain and production?

When we look to the key trends in the global automotive industry the move is tending towards greater collaboration. Previously the automotive industry can best be described as a "producer-driven" (Built to stock) supply chain with multi-layered production systems that are organised hierarchically into tiers. As changes in automotive production and distribution occur, new logistics practices must be established. The logistics industry is being required to customize services to the supply chain demands of global companies that, in turn, need to evolve into companies that offer customized products to consumers.

Supply chain integration is now regarded as an indispensable element for success in manufacturing, and it is believed that supply chain superiority will provide a decisive competitive advantage. And as integration increases, joint resource dedication will follow. In the new information-based economy, firms compete on the basis of supply chain competitiveness rather than as individual entities. Industrial supply chains that are able to minimise frictions between the participants will gain competitiveness through price reduction and speed of response. The ideal being the creation of a dynamic and flexible network of Customer/supplier relationships and information flows that is activated by customer demand and can respond rapidly and reliably to consumers’ preferences.

2. Why are Car makers shifting from Built to Stock to Customized cars (Built to Order)?

The automotive industry and the logistics industry are evolving concurrently. Both industries are shifting towards customized, information based processes with a global scope. There is a growing demand for personalized goods to replace those that are mass-produced. Consumers clamor for goods that fit their needs and their specifications.

3. What are the challenges of Built to order processes on the whole Supply Chain process?

The transition to built to order in the automotive industry will pose a challenge on the planning processes and leads to an increased use of Advanced Planning Systems i.e. of computer based decision support systems, which rely on sophisticated methods of Operations Research. As the number of variants increase, the problems of planning will surface on the shop floor. The large number of variants means, demand
fluctuation, variation of production rate and increase in accuracy of due date are the main challenges that come with the built to order process.

4. How to optimize resources (Labour, Material and Equipment) on the shop floor in the ever demanding automotive industry with short lead time, high quality and many product variants?

Using Integrated Product and Process Engineering (iPPE) can any automotive manufacturer optimize the resources with in a very short time as the iPPE is an intelligently designed form of creating and processing master data for design, construction and production. The iPPE structure collects all the data for an entire product life cycle in one integrated model. It is particularly suited to products with many variants, like the automotive industry. One can use iPPE to document data, and later reuse and update it, from early phases of the product’s research and development process. You can represent a complete production model because iPPE allows you to keep the master data for Bill of Materials (BOMs), routings, and line design in one model.

5. How to optimize assembly lines in automotive industry as the number of car variants increase dramatically?

The sequencing procedures can be view in two ways, one from the departments view and the other is from the inter departments view. Hence considerations for sequencing may vary from the point of view we are addressing the problem. In this thesis we saw sequencing within final assembly shop with a case study by taking various departmental considerations and sequencing within departments theoretically. The steps to determine the model mix percentage and how to calculate it has been thoroughly discussed in chapter 7. The takt based scheduling system, which is described thoroughly in chapter 7 has been used to determine the assembly sequencing.

6. How to implement Model Mix planning and Assembly Sequencing using SAP APO Module?

To implement the Model Mix Planning and Assembly Sequencing the following steps have to be observed carefully.

i. Maintaining Master Data (iPPE). Material, Product and Process have to be modelled in to the system.

ii. Calculation of product mix percentage

iii. Integrating the master data to optimize the assembly sequencing
7. What are the strengths and weaknesses of SAP APO automotive module?
I have tried to summarize the advantages and disadvantages of the SAP APO repetitive manufacturing module as follows. The system is evaluated in two aspects, the first is in maintaining master data and the second is in planning processes on the basis of master data. Planning processes in APO are made on the basis of production processes model (PPM) or integrated product and process engineering (iPPE), the two methods to maintain master data. Disadvantages of PPM planning process.

i. This modelling method is not advisable for complex shop organizations, like automotive industry

ii. It is only for pure make to stock production.

iii. It doesn’t take sales data into consideration. Planning is based on these two requirements, sales order quantities and planned independent requirements.

iv. When planning APO does not take the various change statuses of the master data into account, which you maintain in the system.

v. Scheduling is using lead time.

The iPPE comprises the product variant structure, process structure and line design within a single model.

Advantages of planning processes using iPPE:

i. The master data enables to handle multiple product variants. Data for configurable (make to order) products can be managed.

ii. Suitable for products, which are made to with reference to sales order (Make to order repetitive manufacturing)

iii. Data for non configurable (make to stock) products can be managed.

iv. It can be used for make to stock production and for make to order repetitive manufacturing with configurable products

v. Complex shop organizations, processes and many product variants can be modelled easily in a single model.

vi. The planning procedure is not based on lead time scheduling, like the PPM, but on takt based scheduling.
The disadvantage in working with this process is it can not use pull lists, event-controlled kanban or kanban with planned orders for the products.

Some weak points of SAP APO repetitive manufacturing module are:

i. The product mix analysis is not included in the SAP APO Repetitive Manufacturing Module. Hence, one must calculate the product mix percentage before he/she began to solve the production planning process using SAP APO. The system doesn’t calculate the model mix percentage even though the sales data and other business aims are already with in the system. The model mix percentage should be determined by separate software (usually excel sheet) developed by the specific company by taking the sales and other important data into consideration.

ii. Once resources or products are attached to the model editing is hardly possible.

The advantages in planning processes with SAP APO repetitive module are:

i. We can plan large number of variants and resources with in few minutes according to specific customer demand.

ii. Resources with in complex shop organizations can be planned instantly.

iii. Large number of orders can be planned easily.

iv. Planning can be updated from time to time as the need arises (from shift to shift, hours to hours….)

In general as it is tried to see the strong and the weak points of the repetitive manufacturing module, I recommend the SAP APO repetitive manufacturing module will be profitable if it is implemented in automotive industries. Currently there is no other standard software at the scale of SAP APO Automotive module.

I suggest the following topics for future researches.

1. How to create sequencing between departments?
2. What is the economy of scale of Lean manufacturing?
3. How to handle unknown situations in an efficient way within lean manufacturing environments? Example: Natural disaster, Fire, war, fluctuation in stock markets, etc.
4. Can Kanaban system be integrated in planning process using iPPE?
10. Implications of research

Previous approaches for balancing mixed-model assembly lines rely on detailed forecasts of the demand for each model to be produced on the line (model mix). With the help of the anticipated model mix a joint precedence graph for a virtual average model is deduced, so that the mixed-model balancing problem is reduced to the single-model case and traditional balancing approaches can be employed. Today's ever increasing product variety often impedes reliable forecasts for individual models. Instead, forecasts for the estimated occurrences of each product feature (e.g., percentage of cars with air conditioning) are merely obtainable. This problem is addressed in this thesis by the built in model mix planning and assembly sequencing in SAP APO Automotive module.

In a mixed-model assembly line, setup times and costs are reduced sufficiently enough to be ignored, so that different products can be jointly manufactured in inter-mixed product sequences (lot size of one) on the same line. In SAP APO the resources can be optimized in production of different variants of cars on a single line with in a matter of few minutes as compared to months in the traditional system. The system is well assessed and its weakness and strengths are mentioned for automotive companies to have a clearer view before implementing the system.

This thesis is unique in giving clear insights into the automotive planning system by addressing the following questions.

1. How model mix planning and assembly sequencing can be effectively implemented in automotive industry using SAP APO?
2. How planning can be done effectively using the iPPE (Integrated product and process engineering) structure?
3. What are the things to be considered before implementing the iPPE (Integrated product and process engineering) structure?
4. What are the advantages and disadvantages of SAP APO automotive module?
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