FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Desenvolvimento e implementação prática de metodologias de aprovisionamento de materiais

Procurement strategies for late customization of complex products

Diogo Azevedo

Mestrado Integrado em Engenharia Eletrotécnica e de Computadores

Supervisor: António Paulo Moreira

Company Supervisor: Tiago Brito e Faro

January 22, 2018

Resumo

Em ambiente de produção industrial de baixo volume de produtos complexos e variados, assegurar que todos os artigos necessários à montagem de um produto final estão sempre disponíveis assume um carácter vital no funcionamento de uma empresa, uma vez que garante o funcionamento contínuo de uma linha de montagem. É frequente serem lançadas ordens de compra aos fornecedores tardiamente ou surgirem atrasos do lado do fornecedor que levam a que prazos de entrega de um produto final não sejam cumpridos devido ao facto de os artigos necessários à montagem do mesmo não estarem disponíveis. Atrasos na expedição de um produto para o cliente podem implicar que a máquina que iria ocupar o posto de montagem da máquina que não foi expedida, irá sofrer também um atraso sem que a sua produção tenha se quer começado, originando um efeito de bola de neve.

A empresa onde este projeto foi desenvolvido produz máquinas complexas e tem vindo a implementar uma estratégia de customização em massa, criando vários módulos que podem ser aplicados em vários modelos de máquinas diferentes e oferecendo ao cliente a capacidade de customizar o produto final a partir de uma vasta oferta de opcionais. Esta mudança de paradigma melhorou a imagem da empresa perante o cliente, mas, simultanemante, criou vários desafios operacionais, nomeadamente dificuldade em prever a data de entrega para uma nova encomenda, bem como dificuldade em cumprir o prazo de entrega previamente estipulado, demonstrando alguma incapacidade em gerir os artigos necessários à montagem de um produto altamente customizável.

Esta dissertação insere-se num projeto de melhoria contínua desenvolvido numa empresa de produção industrial, essencial para atingir o objetivo de crescimento num futuro próximo a que a empresa se propôs. Os objetivos para este projeto consistem em aumentar a velocidade da cadeia de abastecimento da linha de montagem de produtos standard e em reduzir o nível de ruturas de inventário na fase de "late customization" dos produtos standard.

Este projeto foca-se na fase de "late customization" do processo produtivo de uma empresa industrial. Um sistema integrador que permite a gestão de fornecedores é desenvolvido neste projeto e abrange várias etapas desde a classificação de materiais necessário à montagem dos opcionais até à seleção e avaliaçao de fornecedores. É apresentada uma metodologia para a classificação dos artigos necessários à montagem dos produtos na fase de "late customization". Esta classificação baseia-se na quantidade consumida e na criticidade e é feita através de uma análise ABC-XYZ. Os artigos são agrupados em conjuntos e para cada um desses conjunto é proposta uma estratégia de aprovisionamento. O sistema apresentado também inclui um processo para seleção e avaliação de fornecedores. A manutenção e desenvolvimento da colaboração entre fornecedor e comprador também são abordadas neste projeto.

A implementação da metodologia proposta permite diminuir o tempo de resposta da empresa ao mercado uma vez que promove a rápida disponibilidade dos opcionais mais consumidos e críticos, através da implementação e desenvolvimento de estratégias de colaboração adequadas ao contexto de negócio.

Abstract

In a low volume and high variety industrial manufacturing environment, it is notably relevant to ensure that all the items necessary for the assembly of a product are available and that production is never interrupted. Frequently, items are ordered to the supplier tardily and express deliveries are required and, more often than expected, the shipment of a final product is delayed due to items being out of stock, i.e., not available to be assembled. Delays in the shipment of a final product may implicate that the production area dedicated to the next machine to go into production will be occupied, resulting in a delay of the following machine, creating a snowball effect.

The company where this project was developed implemented a mass customization strategy, creating interchangeable modules to be assembled in various machine model's and offering the client the capability to customize the final product from a vast range of options. This shift of paradigm improved the image of the company on the eyes of the customer, but at the same time created multiple operational complications, namely difficulty in predicting the delivery date of an incoming order and difficulty to obey the previously stipulated delivery date of a machine, demonstrating a certain inability to manage all the items required to assemble customized products.

This dissertation is part of a continuous improvement project developed in an industrial manufacturing company, critical to the achievement of the expected growth for the near future. The objectives for this project consist in increasing the speed of the supply chain of the standard products assembly line and in reducing the level of inventory shortage in the late customization phase of standard products.

This project focuses on the late customization phase of the manufacturing process of an industrial company. An integrative framework for the management of suppliers is developed in this project, encompassing various stages from the classification of materials required for the assembly of optional equipment to the suppliers selection and assessment. A methodology for the classification of items required for the assembly of the products on the customization phase is presented. The classification is based on quantity of consumption and criticality and is performed through an ABC-XYZ analysis. Items are clustered into groups and for each group a purchasing strategy is suggested. The presented framework also comprises a procedure for the selection and assessment of suppliers. The maintenance and development of the relationship between buyer and supplier are also approached by this project.

The implementation of the proposed methodology can increase the speed to market of manufacturing companies, since it promotes a rapid availability of the most consumed and most critical optional equipment, by the development of the most suitable collaboration strategies.

Acknowledgements

It is my pleasure to acknowledge all those who supported and encouraged me with this project. First, to the company for trusting in me and giving me the opportunity to develop this project. Special thanks to Dr. Inês Moreira for the friendship, trust and guidance through this important and defining time that I spent in the company. Thank you to Eng. Tiago Faro for giving me this opportunity to work and learn in such an important company and also for trusting me with this central project. Thanks to Mr. Rui Moura, Mrs. Cristina Lima, Eng. Rui Neto and Eng. André Silva for the patience and for being company's living encyclopedias.

I would like to thank my supervisor, Eng. António Paulo Moreira , from Faculdade de Engenharia da Universidade do Porto, for accepting this task of helping me during the development of this work and for always being available.

Thank you to my uncle Américo for all the support, all the help and opportunities along these last years.

I would like to thank my friends, essentially for being my friends and for being everything that friends must be.

Special thanks to my parents and sister for all the support, care, concern and for being present in this long journey.

Finally, I would like to thank Raquel, for being the best girlfriend one could ever ask for and for being by my side for so long...

Diogo Azevedo

*"I think it's very important to have a feedback loop,
where you're constantly thinking about what you've done
and how you could be doing it better."*

Elon Musk

Contents

List of Figures

List of Tables

Abbreviations and Symbols

ATO	Assemble-to-Order
BI	Business Intelligence
BOM	Bill of Materials
CODP	Customer Order Decoupling Point
CPFR	Collaborative Planning, Forecasting and Replenishment
CI	Commonality Index
ERP	Enterprise Resource Planning
ETO	Engineer-to-Order
IS	Information System
JIT	Just in Time
JITP	Just in Time Purchasing
MRP	Manufacturing Resource Planning
MTO	Make-to-Order
MTS	Make-to-Stock
MC	Mass Customization
OEM	Original Equipment Manufacturer
PDCA	Plan, Do, Check, Act
SKU	Stock Keeping Unit
SME	Small and Medium-sized Enterprises
SRM	Supplier Relationship Management
SS	Solution Space
VMI	Vendor Managed Inventory

Chapter 1

Introduction

This document is a dissertation for the Master Course in Electrical and Computer Engineering at the Faculty of Engineering of the University of Porto. It was developed in collaboration with a manufacturing company[1] that focus on designing, developing, manufacturing and installing state-of-the-art machine tools.

In this chapter this project is contextualized, the framework of the project and its objectives are presented, along with the methodology that was adopted for its execution. In the last subsection it is included the document's structure.

1.1 Context

The company that supported this research manufactures complex products exporting to more than 40 countries worldwide and 80% of its turnover is outside Portugal. Despite the fact that the majority of the company's revenue comes from exportation the company has the biggest market share in its mainland.

Due to the strategy of the new management, a 20% growth in sales is expected for next year, and to support that growth it was delineated that the throughput time of the plant should be reduced and, consequently, the production capacity should increase. The biggest challenge in order to achieve better operational performance consists in reducing delays on the suppliers' delivery of critical items required for the assembly of the final product.

1.2 Framework of the project and objectives

Nowadays manufacturing companies are facing new challenges that have arisen as a consequence of globalization. Part of these challenges relate to the fragmentation and change of customer demands, increased urgency for customized products, rapid technology innovations and consequent reduction of product life cycle [6, 7]. Therefore, in order to stay competitive, manufacturing companies are obliged to efficiently provide a varied portfolio of products, aimed to fit distinct

[1] For confidentiality reasons, the name of the company is not referenced.

customer needs and constantly introduce new features [8, 9]. A varied portfolio means that the company will need to manage multiple stock keeping units (SKU) and be able to quickly respond to variations in product configurations. These challenges are even more demanding for a small or medium enterprise (SME) both in strategical and operational terms in comparison to large scale enterprises.

The company where this project was developed went through a profound change in the past decade. There was a strategy shift that led the company into the mass customization (MC) path. This shift meant that instead of offering completely standard products, the company would start to manufacture and sell highly customizable ones. In reality this meant that the company would be able to offer a product that fits the customers' needs and still benefit from economies of scale.

As of today every product sold by the company is a customizable one. It can either be a completely custom designed machine developed under an engineer-to-order (ETO) environment, or a machine that has a standard body but can be customized with multiple options, similar to the process of buying a new car where the customer can choose whether or not he wants leather seats or satellite navigation. This dissertation will focus on the latter, where the manufacturing process consists in producing the basic product (without any customizable or configurable feature) and then on the last phase all the options selected by the customer are assembled to the machine, under an assemble-to-order (ATO) environment.

Delivering machines past the scheduled date is a difficulty faced by the company once it is recurrent that suppliers fail to deliver components on time, having an affect not only on the machine that the component is intended for, but also on the machines that were scheduled to be assembled on the same production station immediately after the first machine was shipped. The development of this project aims to reach a solution to this issue by responding to two main objectives:

- Increase the speed of the supply chain of the standard products assembly line;
- Reduce the level of inventory shortage in the late customization phase of standard products.

To accomplish these objectives it is fundamental to apply a suitable methodology, one that suits this particular context of business. In the context of this project the following research questions were identified:

- RQ1: How to classify the items needed for the assembly of the optional equipment?
- RQ2: How to segment suppliers according to the most appropriate purchasing strategies?

By answering the previous questions, the opportunity to replicate the same methodology to all the items involved in the late customization phase arises.

1.3 Methodology

The improvement in performance of the supply chain responsible to feed the late customization phase of the production process requires the development of two distinct but also complementary areas.

The first area corresponds to the design of the solution. In this phase, a method for the classification of the required parts for the customization of a product is selected and for those parts it is proposed how they should be supplied.

The second area is related to the segmentation of suppliers. This area is divided in two components, operational component and strategic component. The operational component is linked to the definition of the supplying strategy for each supplier depending on the relevance of a certain supplier to the entire operation. The second component is related to the supplier development plan and aims to achieve competitive edges by benefiting from supply chain integration and establishing partnerships with core suppliers.

Figure 1.1 illustrates the methodology implemented in this project. The framework is inspired in the work proposed by [10], but different techniques were applied during the development of this project. The system present in this work comprises a continuous improvement module which closes the loop between the first step of the process (Items classification) and the last step (Supplier assessment and development). This module highlights the necessity of continuously checking the current process in order to detect improvement opportunities and prevent stagnation.

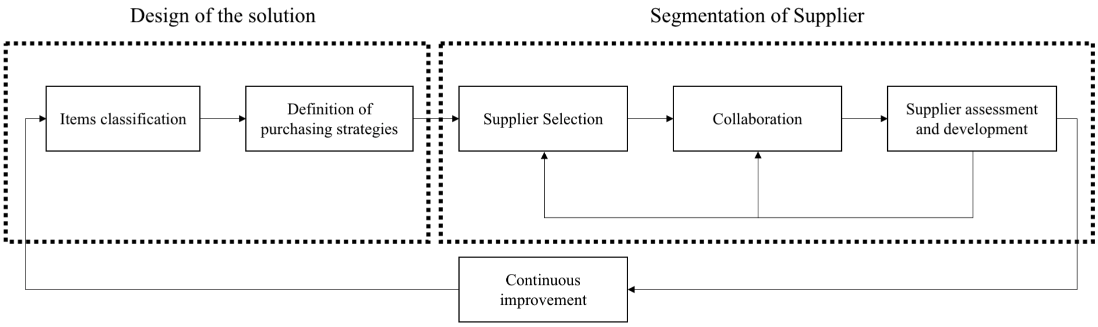

Figure 1.1: The proposed framework

1.4 Document structure

The dissertation extends for 6 chapters, where the context and methodology for the development of the project are explored. This paper is outlined as follows.

This chapter, of an introductory nature, aims to introduce the project, contextualizing it and defining its objectives. In Chapter 2, a theoretical review of the structural concepts of the project is performed. Chapter 3 refers to the items classification and presents the methodology utilized to classify the items and the suggested collaboration strategy for each item. In Chapter 4 a framework for the segmentation of suppliers is presented. Chapter 5 aims at discussing the main conclusions about the project and presents guidelines for future work.

Chapter 2

Theoretical Review

In the present chapter the theoretical concepts that serve as the foundation for this project are revisited, as well as relevant previous research. The themes that are pertinent for the contextualization of this work are presented here. Mass customization is a strategy implemented by the company and is linked to concepts such as Modularization, Postponement and Customer Order Decoupling Point.

2.1 Mass Customization

In today's business environment more and more customers are demanding individualized products and for that reason challenging traditional mass production [11]. This demand for highly individualized products results in a change of paradigm from a stable and highly predictable market into a volatile and unpredictable one [12].

The goal of Mass Customization (MC) is to deliver individually customized products at an efficiency and cost similar to mass production, responding to the increasing customer demand for inexpensive customized products [13, 14, 15]. This concept has the ability to couple the high efficiency of mass production with the capability of a company to offer highly customized products. As many small and medium enterprises (SME) produce high variety in lower volumes, MC surfaces as an alluring business strategy, allowing them to benefit from reduced delivery times, more rigorous cost estimation and less expenditure on specification through increasing standardization of customized products, i.e., restricting product variety [16, 17].

Every customization operation is executed within an established solution space (SS), characterized by stable yet flexible and responsive processes [18]. SS specifies all the design parameters' possible permutations that allow for the fulfillment of the customer's needs [19]. SS development expertise is essential for MC firms [20].

2.2 Modularization

Modularization stands for a strategic product design process adopted by original equipment manufacturers (OEM) in order to broaden product variety without severely affecting production costs [21, 22, 23]. A modular product approach allows for the standardization of product components. Standardized product components can be shared and applied in a variety of different products, promoting more frequent new product releases by combining different modules from the available designs and, consequently, increase the speed to market of a new product [21, 24].

A product is a complex system, resulting from the combination of multiple interacting parts. Modularization presents itself as a mean of reducing the system's complexity, implying that "the product should be designed as a set of sub-assemblies (sub-systems) so that their assembly constitutes a new product" [21]. This sub-systems architecture enables greater flexibility for product design engineers, sales staff and customers to assemble and tailor-make product solutions. One golden rule of product modularization is that each sub-system must perform a defined function and it can be modified separately without influencing other sub-systems [25].

The faster new product development process that results from modularization is only possible due to the maximization of the use of existing standardized component units. As a consequence of this maximization, results savings in both financial and human resources usage [26].

The OEM can approach modularization through two different strategies - the integrator role (the OEM designs the module, maintaining module control) and the modulariser role (module control is handed over to fist tier suppliers that have the competences required to provide modular solutions) [27, 28].

Many examples of modularization implementation can be found in the literature. Typical examples of modularization include Sony Walkman, sold in 160 variations by combining modular components, Ford Motor Company designing its truck and automotive engines with multiple common parts, and IBM creating customized programs combining modules of routines [29].

2.3 Postponement

Postponement is defined by Van Hoek (2001) as the following:

> "Postponement means delaying activities in the supply chain until customer orders are received with the intention of customizing products, as opposed to performing those activities in anticipation of future orders." [30]

This concept was first introduced in [31], where the author noticed that a product has a tendency to become differentiated when its production process reaches the point of purchase, i.e., as it streams down the supply chain. A differentiated product promotes marketability, but at the same time the complexity of the production process is increased [26]. This incremented complexity in the manufacturing process can be solved by shifting the "point of departure" for the differentiated product closer to the point of purchase, allowing for the consolidation of a base product.

Maximizing the common processing requirements and delaying the "point of departure" reduces forecast errors, since uncertainty is controlled and production decisions correlated to a particular demand are delayed [26]. In [32] a survey was conducted and companies voted the following as the main drivers of postponement (ordered from the most important to the least important) [33]:

- Raising delivery reliability;
- Improving speed of delivery;
- Improving inventory cycle times;
- Lowering logistics cost;
- Lowering obsolensce risk;
- Improving product customization.

In this regard, Postponement consists in a "value added process for a set of end products whereby the common processing requirements among them is maximized. The customized or unique processing requirements for each product variety is delayed (or postponed) as much as possible in the value added process" [26]. Because of that, Postponement presents the possibility of combining scale advantages without jeopardizing the variety of products, i.e., scope advantages.

A classical example of the benefits of Postponement is presented in [34] where Hewlett-Packard made a decision of transferring the packaging process from the manufacturing facility to the local distributor. Since the final packaging of the printer varies from country to country, mainly due to different languages spoken in the destination countries, HP centralized the production of a standardized product, delaying the value added customization process of placing the printer inside a market specific package. This decision led to important inventory savings, since the decision of customization started being triggered by demand.

2.4 Customer Order Decoupling Point

Customer Order Decoupling Point (CODP), also recognized as order penetration point, is defined in [35] as the point where the product is tied up to a concrete customer order. The position of the CODP in the value chain distinguishes manufacturing strategies such as Engineer-to-Order (ETO), where products are engineered according to customer's specific requests, Make-to-Order (MTO), where predesigned and ready for use parts are utilized for manufacturing and posterior assembly of the product variants, Assemble-to-Order (ATO), where activities of engineering and manufacturing are executed based on forecast and the assembly process consists in assembling subassemblies from stock[36], Make-to-Stock (MTS), where all the processes (engineering, manufacturing and assembling) are based on forecast.

In [1] CODP is defined by the authors as the point that detaches the decisions made under uncertainty from decisions made under certainty in respect to customer demand. In Figure 2.1,

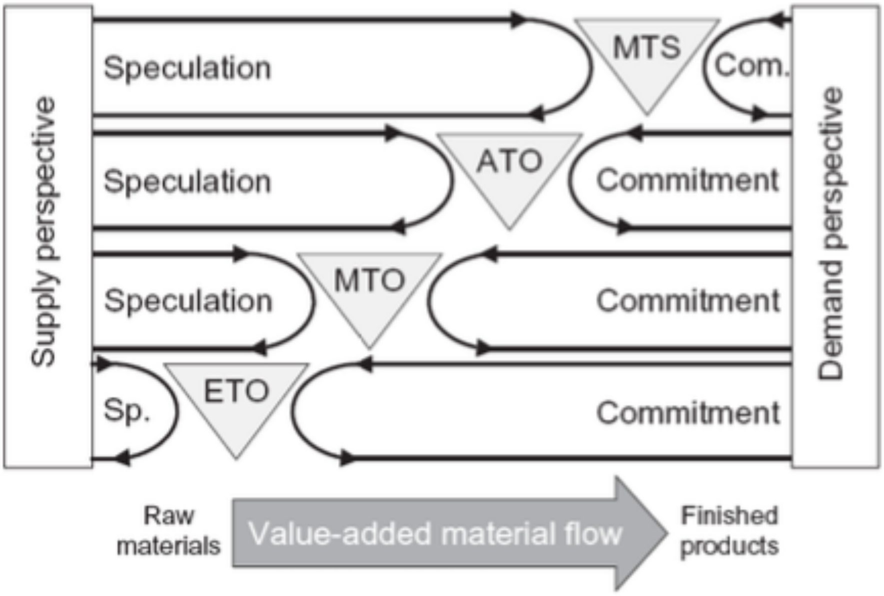

Figure 2.1: Sequential approach to the CODP concept (extracted from [1])

speculation refers to activities based on forecast, while commitment is related to customer-order-driven activities.As a result, CODP is represented by the triangles placed between speculation and commitment in the value-added material flow.

In order for a company to provide multiple product varieties, a modular product design promotes the separation between manufacturing and assembling activities [37]. Therefore, components or modules can be produced or outsourced based on forecast and assembled upon customer's requirements [38], allowing the postponement of the CODP closer to the customer [36].This strategy targets the capitalization on standardization and modularity, attaining economies of scale [39, 36].

2.5 Inventory Classification

In account of constant change in technology and more demanding customers, products are becoming more customizable and, as a consequence, more complex. This leads to shorter product life cycles and wider product ranges. Managing all the parts and items that a company needs in order to make a product is also more complex [40].

The most common inventory classification analysis performed in industry is the ABC analysis for the financial assessment of the value of an item [41]. The simple and straightforward utilization of this analysis is the primary reason for its popularity. It is only necessary one criterion to classify the items [42].

ABC analysis is often supplemented by an additional classification analysis, i.e., parts are categorized by employing two criteria in the form of a matrix model. XYZ analysis is frequently utilized as an extension of ABC analysis. This analysis is based on "the prediction accuracy of the demand, that can be operationalized from the coefficient of variation as a measure of fluctuation" [41]. Other analysis that can be applied as a complement of the initial ABC analysis is FSN. FSN stands for "fast moving, slow moving, no movement" and classifies inventory based on inventory turnover [41, 43].

Criticality is also a very common criterion for inventory classification. In [44] the demand for spare parts is classified into "critical" and "non-critical", depending on whether a certain demand can be covered by the inventory or not. The same author presents an additional classification based on criticality in [45], where the number of machines in which a particular part can be installed is the criterion. According to this empirical study an item is considered to be more critical if it is installed in a multitude of machines, since an inventory shortage of the item could simultaneously affect a larger machine population. VED analysis enables the classification of parts into "vital", "essential" and "desirable". This analysis is usually utilized to classify spare parts required for industrial maintenance and designates the need for keeping inventory of spares; if a vital item is not available then it is expected to occur serious productivity loss. VED is also commonly applied in the management of medicines in a hospital [46].

2.5.1 ABC Analysis

The ABC analysis is a method that enables the classification of a set of articles in three classes: A class, B class and C class. In A class are comprised the most relevant items, in B class are the items with medium relevance and in C class are the least relevant items.

The ABC analysis is based on the Pareto principle which illustrates that for many events the following occurs: 80% of effects are reached by 20% of the causes. Items with high sales are categorized as A-articles, while C-articles have low consumption [47]. This segmentation is presented in [2]:

- A items which constitute roughly 15% of the total amount of items (a small minority), portraying the most relevant items;
- B items which represent the following 35%, with items of medium importance;
- C items which are the remaining 50% of the product list, presenting the ones that are the least valuable.

In Figure 2.2, an example of a typical distribution of items between the three categories is presented.

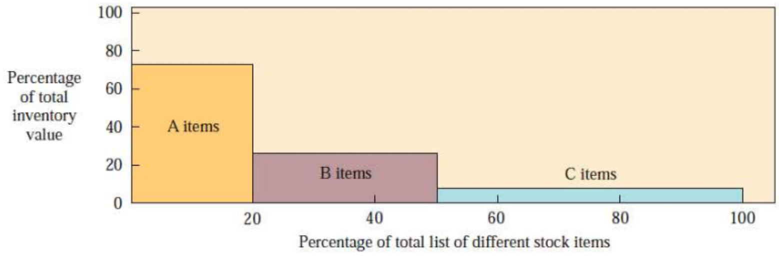

Figure 2.2: Example of items classified by ABC analysis (extracted from [2])

The criterion utilized to measure the relevance of each item differs between each industry or even the analysis purpose. Some authors distinguish multiple ABC analysis based on different criterion, as seen in Table 2.1:

Table 2.1: Different ABC analysis (extracted from [5])

Criterion	Reasons
Stock Value	Amount of capital lockup Stock reduction potential
Quantity of consumption	Order picking Warehouse organisation Storage Strategies
Turnover ratio	Sales volume Assignment in warehouse
Volume of sales	Amounts of coverage Selection of scheduling methods
Service level	Safety stock Customer satisfaction
Reference volume of suppliers	Supplier selection
Amount of demand	Material requirements planning Sales volume

In an industrial environment this analysis has some limitations as the value of parts that are both highly critical and low in consumption may be overlooked and periodic updating and review is critical [48, 5].

2.5.2 XYZ Analysis

The XYZ analysis is often utilized as an extension of the ABC analysis [49]. In an ABC analysis, typically the C class items wouldn't have any parameters delineated for planning since they represent little economical significance. Accordingly, there is a need to classify items not only based on their value, but also based on the consistency and predictability of the consumption [40].

In Figure 2.3 is represented the usual patterns for each items' class fluctuation.

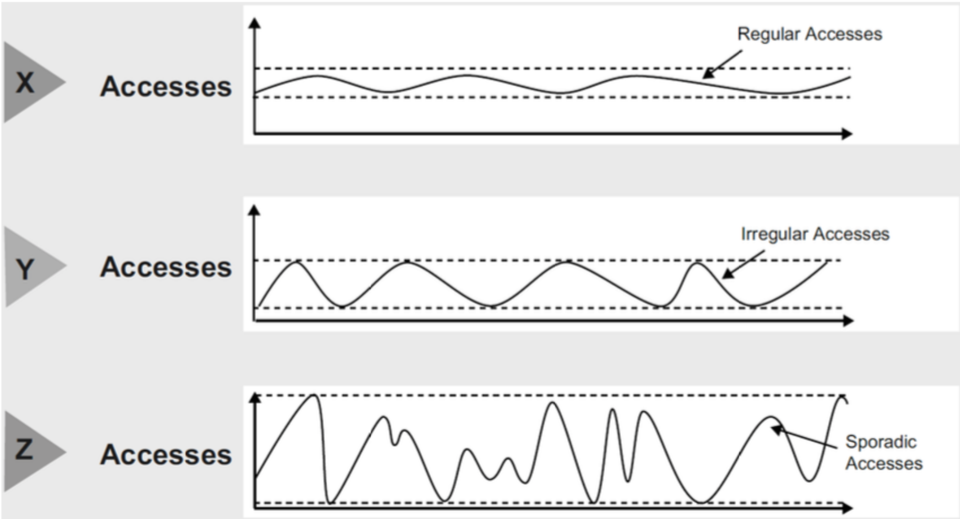

Figure 2.3: Example of characteristic fluctuation of each items' class (extracted from [3])

The XYZ approach, similar to the ABC one, segments the items in three classes [47, 3]:

- X items present minor fluctuations around a constant level of demand. Demand forecasting for these items is generally very accurate;
- Y items are characterized by a demand that is neither constant nor sporadic, mainly due to trend-moderate or seasonal reasons;
- Z items consumption is very irregular. In some cases Z items present no demand, increasing the difficulty to forecast their demand.

2.6 Supplier Relationship Management

Competing in a global market while having to deliver complex products customized to specific customer's needs has led companies to realize that effective supply chain management is a crucial factor in order to remain competitive [50]. The purchasing task in a company is vital for the entire supply chain performance and sees its influence increasing with the rise of purchasing and outsourcing expenses, which, in turn, leads to the companies looking at Supplier Relationship Management (SRM) as a way of improving their efficiency. SRM involves several dimensions such as determining the more adequate purchasing strategy for each item, supplier selection, management and collaboration [10].

There are two main approaches when it comes to purchasing strategies. The first one is the competitive purchasing strategy, where suppliers compete between each other and buyers benefit from the opportunity of buying at a lower price. The other strategy is considered to be a modern purchasing approach and is often labeled as cooperative approach, where buyer and supplier constitute a strategic relationship and collaborate with each other aiming towards a long-term objective [51]. The collaborative approach generally has costs associated with supplier evaluation and supplier development programs, so it is fundamental that the ideal purchasing strategy is determined according to the company's needs [52].

In order to keep a continuous flow along the manufacturing process it is fundamental that the purchases department ensures that all the necessary items are available when they are needed for assembly which is not possible if there's no effective process for selecting a good supplier. When a purchasing manager is evaluating and posteriorly choosing a supplier there are two issues that arise. The first one consists in the selection of the right criteria for the evaluation of suppliers [53], while the second one consists in the assessment and application of methods for the evaluation of suppliers, preventing that the wrong supplier is selected [54].

In many industrial environments, suppliers are encouraged to be involved in improvement programs aiming to improve quality, reduce costs and be part of joint development of new products or modules. Over the last three decades, many progresses have taken place in collaborative working in supply chains. The foundation of this logic of collaborative work has been the idea that by sharing information and by being involved in creating joint plans, both the supplier and the customer can benefit [55]. In literature, the most common collaboration techniques are Vendor managed inventory (VMI), Collaborative planning, forecasting and replenishment (CPFR) and Just-in-time purchasing (JITP) .

- In **VMI** the supplier has the responsibility to manage the customer's inventory on the customer's behalf and manages the flow of product into the customer's operation. Periodic exchange of information about the usage of the inventory occurs, being the supplier the one who holds the responsibility of knowing what quantity to ship and when to ship it [55];

- **CPFR** is an extension of the VMI strategy, taking the collaboration part further. In CPFR both the supplier and the customer work together, generating a joint forecast for future consumption and sharing information in a strategical and thrust based alliance. It is a very common practice in the retail environments, but many of its features can be applied in a manufacturing supply chain [55];

- **JITP** makes the customer's JIT operation viable. JIT is based on the idea that no activity should happen in a system unless it is needed. According to this technique, no items should be ordered unless there is a demand triggering those orders [55].

Managing suppliers requires evaluating those suppliers. A supplier's evaluation consists in classifying the supplier according to his competences and performance. The evaluation process has two variants: the first takes place before the collaboration between the two companies takes place and aims at comparing multiple suppliers, the second assesses the supplier's performance during the collaboration in order to evaluate whether or not actions like replacing the supplier or enrolling the supplier in a development program need to take place [56].

Chapter 3

Design of Solution

The aim of this chapter is to present the reasoning behind the classification of items required in the late customization phase of the manufacturing of a machine and propose strategies for the procurement of those items.

3.1 Data collection

The company where this study was conducted manufactures state-of-the-art machine tools. Its portfolio consists of three main product families, namely, press brakes, shears and laser cutting machines. Each product family has already standardized ranges and models that can be configured by the customer by means of selecting from a vast choice of optional equipment. Configurable products are internally designated standard products. A standard product is the one that after being configured is in accordance with a previously established list of options. If the customer requirements go beyond the possible configurations, the company will develop a specially engineered machine according to the exact customer specifications.

For the development of this project data from the family of the press brakes was selected. The press brakes are very complex machines with several ranges and models, and each model has many optional equipment available for configuration which means that the product variability is high. The press brakes' family is divided into three different ranges: CC, QB, QN [1]. CC is an electrical press brake distinguished for its sustained technology and for its fast and energy saving operation, QB is a very fast, flexible and accurate machine while QN is a machine that distinguishes itself for its price/quality ratio. These ranges of machines were chosen for this study because of the very significant part of the company's turnover that they represent, the complexity of the product, the delays that occur frequently during their assembly and the commonality between the items that constitute their optional equipment.

[1] These designations do not have any relation to the actual designations given by the company but for confidentiality reasons these designations were created randomly without any actual meaning or relation to the product itself.

The data collection was carried out through the company's enterprise resource planning (ERP) and internal database and contains sales data, bill of materials (BOM), product configurator's data and data from the internal business intelligence (BI) software.

Gathering all the information needed for the following analysis constituted a significant challenge and took several months due to limitations on the product configurator software and also due to inaccurate BOMs. These limitations determine that every time a machine is configured there is a need to manually check the resulting BOM and to verify the orders generated by the manufacturing resource planning (MRP) software. These manual checks often result in changes of the items that will be assembled in a certain machine, which, as a consequence, lead to incorrect information in the database. In order to prevent analyzing incorrect data that would lead to incorrect conclusions, regular meetings with production planning engineers and product development engineers took place. These meetings served the purpose of verifying the accuracy of the acquired data.

The sample size refers to sales data of standard press brakes within a 1-year period (2017). A larger period could have been taken into account but then the analysis would include data from optional equipment that is no longer available and might also reflect an outdated market trend, since there was a significant shift in the kind of machines that customers are currently buying (according to the expertise of the directors of sales department).

Each product range has close to thirty configurable options resulting in a vast variety of end products, therefore basically none of the produced machines are identical. This project focus on two crucial optional equipments: numerical controller and safety features. All the machines under the scope of this project need to be equipped with a numerical controller and safety modules (for the protection of the operators of the machine) in order to be able to operate. Each one of these two configurable characteristics comprises many options for the client to choose from. Numerical controllers and safety modules are considered by the company to be two of the most critical of all the available options, due to the price of the materials needed for the assembly of these options in the machine and the distance between the company and some of the suppliers of these materials which often results in items being received after the expected date.

Data from 92 machines was collected and verified. In Figure 3.1 is shown the quantity of machines sold by model.

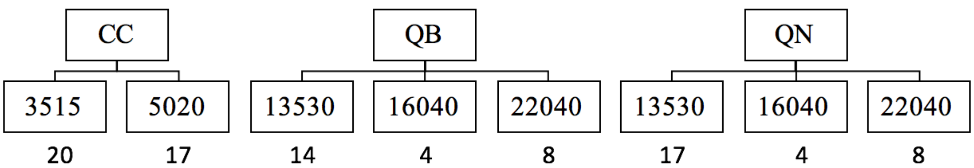

Figure 3.1: Quantity of machines sold by model

In 2017 were sold 37 CC, 26 QB and 29 QN. The most sold machine is the CC3515, followed by the CC5020 and the QN13530.

After selecting which machines and options to study, a baseline was established. The next step consisted in checking what were the different numerical controllers and safety modules available for selection for each machine model. For every optional equipment it was necessary to find what were the items needed to assemble that option on the machine, what was the quantity needed of each items's for that assembly, the price of every item, how it was purchased and who was the supplier. This information was obtained by crossing the data from the BOMs and the ERP.

3.1.1 Data Processing

Concurrently with this project, there was another project related to the the materials management under development. That other project consisted in the development of a Kanban Supermarket where low cost and fast moving materials would be stored. The supermarket is placed next to the assembly line and is managed according to a 2-bin Kanban system. Its materials are ordered manually by the warehouse personnel when one of the two bins is empty. As some of the items required for the assembly of the numerical controllers and the safety modules were covered by the supermarket project, the list of materials collected on the previously collected was filtered and the supermarket materials were not taken into account. This filtering step left 99 different items for analysis.

3.2 Items classification

The item classification is divided in an ABC analysis where items are classified based on their quantity of consumption, and in a XYZ analysis where items are classified based on their commonality.

3.2.1 ABC analysis

The first part of the items classification consists in an ABC Analysis. This analysis was performed according to the criterion of quantity of consumption. An analysis based on stock value could be implemented, but the purpose of this initial component of the classification was to determine what are the items with higher consumption within the time period of the selected data. An ABC analysis based on stock value is relevant when the company needs to classify the items based on capital lockup, but from an operational perspective, there's more value in verifying what are the items with higher consumption.

The first step of this analysis consisted in the determination of the absolute quantity of consumption of each item, followed by sorting the items in descending order according to their consumption. Then the relative proportion of the consumption of each item was calculated. The next step consisted in the calculation of the accumulation of relative contributions to total consumption of all items. For the classification of a new item (without historical of consumption) it is required to utilize a forecast of the demand.

The items were classified in three classes: A, B and C. From the 99 items studied, 33 are A-class items, accounting for 80% of the total quantity of items[2], 29 are B-class items and 37 are C-class items. In Appendix A the entire table with the ABC classification is shown. This analysis exposes the items with higher consumption and classifies them as A-class items. The company needs a well planned strategy in order to manage these items. Risking a stock out of one of these items would mean that production could stop and serious losses could occur, but overstocking these items would incur in a large capital lockup. To add to this question there's the issue that this analysis might overlook some items that despite the low consumption are relevant for the company. For this reason, it is necessary to add a second dimension to this analysis in order to classify the items based on their criticality.

3.2.2 XYZ analysis

XYZ analysis is usually linked to the forecastability of a certain item, i.e., how easy it is to forecast an item, as seen on Chapter 2. X items correspond to the ones that are more easily forecast and Z items are the more challenging ones. This classification is usually achieved by using the coefficient of variation, which is a scaled version of the standard deviation of the historical sales [4]. In Figure 3.2, there's the sales history of an item that has relatively leveled sales with a lot of variability on the left, and on the right is illustrated the historical sales of an item that has seasonality with no randomness. The first one is very difficult to forecast, while the second is easy since the next season will be exactly the same as the previous one. Using the coefficient of variation it would not be possible to conclude that the second item is easier to forecast than the first, since the coefficient of variation is higher on the second series.

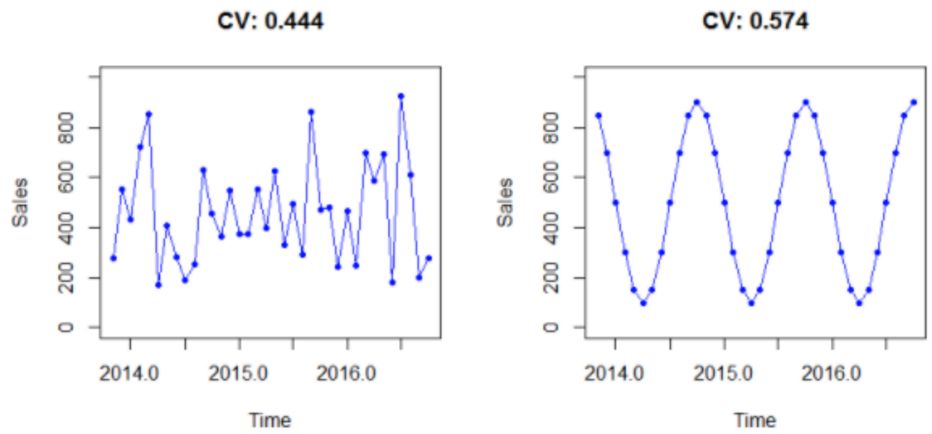

Figure 3.2: Series that exemplify that the coefficient of variation fails as an indicator of easiness of forecastability [4])

[2]The ABC classification usually classifies items according to the distribution present in Figure 2.2, but it was decided by the company that in this particular case 80% of the total quantity of items would correspond to A-class items

Although the traditional XYZ analysis did not fulfill this project's requirements, it was still needed to add a second dimension to the classification.

Items are frequently classified according to a certain risk level. For example, in a hospital a certain medicine may have low consumption or low cost, which in an ABC analysis would lead to this item being considered not important, but this medicine can be critical if one day a patient needs it to survive to some rare poisoning. The same happens in a manufacturing environment where a one cent screw can stop an entire production line.

The criterion utilized for the criticality classification in this study was the commonality of an item, i.e, in how many different machine models can a certain item be assembled into. This concept is similar to the one presented in [45], where the author classified spare parts based on the quantity of different machines in which a particular item could be installed. This criticality criterion is not common in this type of inventory management, being more commonly associated with maintenance spare parts. The power behind this criterion of classification lies within the reason that if an item that is common to many machines is not available, the manufacturing of multiple machines can be interrupted at the same time.

In order to measure the commonality of an item, the quantity of different machine models where a certain item can be installed was counted for all the 99 items under the scope of this study. Then a commonality index (CI) was calculated by dividing the quantity of different machine models where a certain item can be installed by the total amount of different machine models present in this study (2 CC models, 3 QB and 3 QN, totalling 8 different models).

In this project three categories are suggested for the criticality analysis:

- X items are highly critical ones and correspond to items that present a commonality index higher than 0.6 (CI>0.6);
- Y items present a medium criticality with a commonality index between 0.3 and 0.6 (0.3<CI<0.6);
- Z items are not critical and are associated with a low commonality index, inferior to 0.3 (CI<0.3).

From the universe of the 99 items covered by this analysis, there are 20 X-class items, 18 correspond to Y-class items and the last 61 items are classified as Z-class items. According to this classification 20% of the sample is highly critical, and a shortage of these items would most probably affect the assembly process of multiple machines.

3.3 Definition of purchasing strategies

When selecting the most appropriate strategy for the purchasing of a certain item, the company can choose between a competitive strategy or a cooperative strategy. In a competitive strategy the buyer-supplier relationship is dominated by the buyer, the supplier will only sell to the buyer after a competitive bidding process and short-term contracts are established. On the other side, a cooperative strategy is defined by a strategic partnership between buyer and supplier over a long-term contract, the sourcing process is very reliable and supplier is informed about the company's inventory and production plan [10].

The ABC and XYZ analysis performed in the previous sub-chapters are essential for the definition of purchasing strategies. According to each item's consumption and criticality, items are clustered into the following five strategies, present in Table 3.1. JIT, VMI and Supplier Kanban are cooperative strategies, while Short term contract and Single Sourcing are competitive ones.

Table 3.1: Suggested purchasing strategies according to consumption and criticality

<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>X</td><td rowspan="2">J I T P</td><td colspan="2">VMI</td></tr>
<tr><td>Y</td><td>Supplier Kanban</td><td rowspan="2">Single sourcing</td></tr>
<tr><td>Z</td><td colspan="2">Short term contract</td></tr>
</table>

For items that exhibit high criticality and high consumption (AX and AY), a JITP strategy should be implemented. JITP needs a very coordinated operation and commitment between the two sides, but is fundamental to achieve high service levels while maintaining low levels of inventory.

A VMI strategy is proposed for highly critical items with average to low consumption (BX and CX items). This strategy is appropriate for these items because it grants that the customer will have full availability of the critical items, but since these items don't show a significant consumption, the supplier will not incur in excessive capital lockup.

For items with medium consumption and moderately critical the suggested purchasing strategy is a Supplier Kanban. One part of the inventory is held in the customer's plant and the other part is held in the supplier's warehouse. A fixed quantity of order is agreed to and when the customer orders one batch of that item, the supplier can respond immediately.

For the purchasing of items with low risk and medium to high consumption, short term contracts are established with suppliers after intensive price negotiations. For a short period of time the customer agrees to buy a certain item and the supplier grants a high service level by stocking according to a pre-defined forecast.

A Single Sourcing strategy is adequate for items with low consumption and average to low criticality. Since these items are rarely bought, when they are needed the order can be generated by MRP and sent to one of the available suppliers.

3.3.1 Combination of ABC and XYZ analyses

The ABC and XYZ analyses can be categorized by a twofold gradient with 9 positions. In Table 3.2 the 99 items studied in this project are allocated into their respective position according to the previously performed analyses.

Table 3.2: Combination of the results of the ABC and XYZ analysis

	A	B	C
X	17	3	0
Y	6	9	3
Z	10	17	34

Applying the strategies defined in sub-chapter 3.3 it is possible to verify that a total of 23 items (AX and AY) will be purchased according to the JITP strategy, VMI is the chosen strategy for 3 items (BX and CX), Supplier Kanban will be utilized for the management of 9 item (BY), sort term contracts will be signed to control 27 items (AZ and BZ) and the final 37 items (CY and CZ) will be managed with Single Sourcing strategy.

Depending on the accuracy of the production planning, JITP, VMI, Supplier Kanban and Short term contracts are able to grant a high service level, preventing interruptions in the production plant due to the absence of a certain item. Single sourcing comprises more risk, but there are substantial gains in not stocking low risk and low consumption items.

As stated previously, each machine model can be customized by the client by choosing between multiple numerical controllers and two different safety modules. Implementing the purchasing strategies as suggested, the company will be able to ensure that around 65% of the items needed for the assembly of the two options studied here are readily available for manufacturing, but unless it is possible to assemble the optional equipment studied in this project with the readily available items, there is no significant advantage in establishing partnerships and signing contracts with suppliers. It is then necessary to check each optional equipment's BOM and verify if all the components required for the assembly of that optional are not single sourced. In Figure 3.3 the results of the analysis are illustrated (the optional equipment highlighted in green are the ones that can be assembled with the contracted items, while the ones highlighted in orange correspond to the optional equipment that require single sourced items).

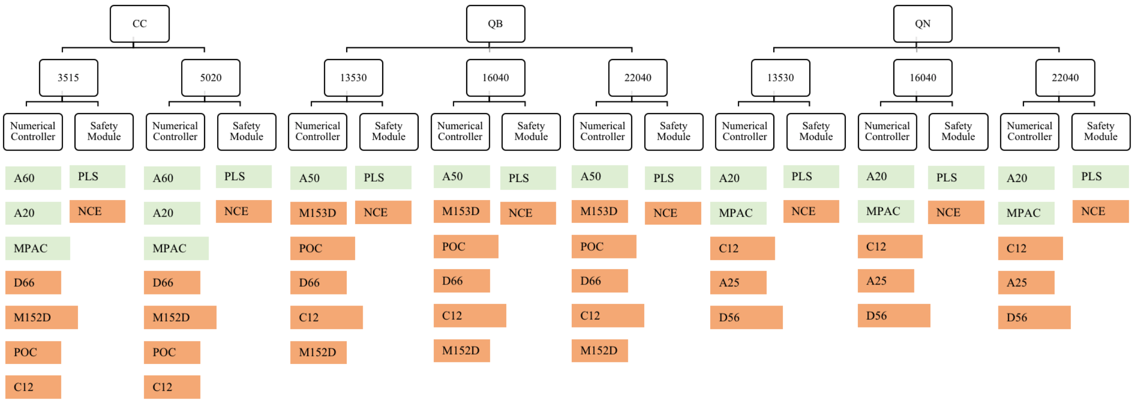

Figure 3.3: Optional equipment highlighted according to its availability

By inspecting the hierarchy present in Figure 3.3 it is possible to state that every model has at least one numerical controller and one safety module available for rapid assembly. This conclusion means that by implementing the proposed purchasing strategy, the company will be able to drastically reduce the speed to market of every machine and provide a delivery date for the machine with increased accuracy.

Chapter 4

Segmentation of Suppliers

In the following chapter the segmentation of suppliers is explored. Topics like supplier selection, assessment and development are delved into and considerations on the continuous improvement of the suggested framework are also taken into account.

4.1 Supplier selection

In the business context of manufacturing companies, a significant portion of capital is spent on supply and supply costs are a very large part of the total cost of the operation, thus making supplier selection one of the most critical elements of supply chain management for several companies. The proposed supplier selection process consists of two steps. In Step 1 suppliers are pre evaluated according to criteria like technical capabilities, brands represented, capacity in being involved in joint product development, capacity of supplying already assembled modules or any criteria relevant for the business context and then are registered into a supplier pool. In Step 2, the most suitable supplier for a certain item , group of items or even a complete module is selected from the supplier pool for collaboration. The type of collaboration established between the two entities should be defined according to the purchasing strategy recommended for the item in Chapter 3. In Figure 4.1 it is illustrated the proposed framework for the segmentation of suppliers.

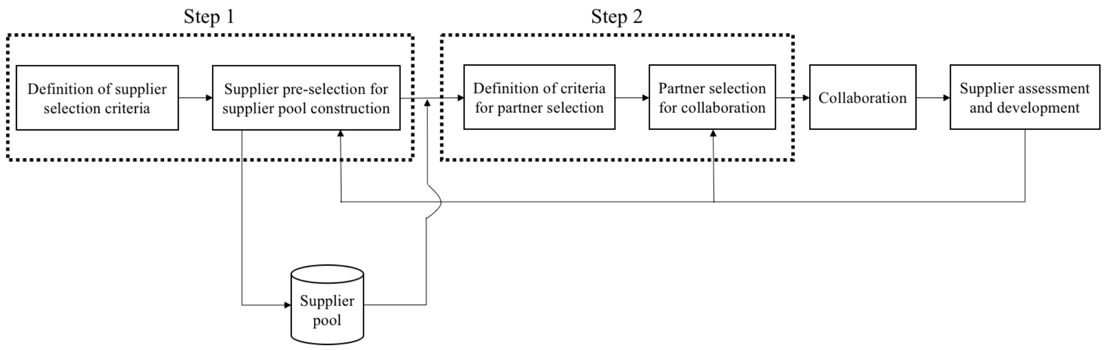

Figure 4.1: Framework for the segmentation of suppliers

Step 1 comprises two stages: definition of supplier criteria and supplier pre selection for supplier pool construction. Building up a supplier pool facilitates the entire supplier management task. It is easier to rapidly supply from a pre selected group of suppliers than to constantly look for suitable suppliers every time a new purchase is required. Another advantage of the creation of a supplier pool lies within the centralization of data and the consequent easiness of managing the details of a new potential supplier. Generally, a supplier pool comprises suppliers that are able to sell similar items or supply complete modules.

Depending on the type of material to be purchased, an audit, sample evaluation, supplier certification and following up the first supply can be required, as illustrated in Table 4.1.

Table 4.1: Supplier's qualification requirements based on type of material

Type of material	Audit	Sample Evaluation	Supplier Certification	Follow first supply
Components	—	X	X	X
Consumables	—	X	X	X
Outsourced	X	X	—	X

The audit comprises a visit to the supplier's facilities for a analysis of the productive process and to verify if the supplier has a process to deal with non-conformities. The audit is mandatory for all the outsourced materials due to their non-standardized nature. An audit must be performed for consumables or components in the event of the supplier not being officially certified. All the materials must go through a sample evaluation performed by the technical department and the first supply must be followed closely by the logistics department in order to grant the conformity of the entire process and that the required quality standards are met.

All the suppliers that pass the pre-selection for the supplier pool are added to the supplier pool.

In Step 2 more detailed criteria are defined in order select a potential supplier for the establishment of a partnership. This phase takes into consideration the cost of the material, ability to be involved in product development or contributing for product improvement, lead time for the supply of materials, ability to supply according to the purchasing strategy defined in Chapter 3, or any criteria defined by the buyer for a specific product or group of suppliers. Due to the high variability of final products manufactured by the company under the scope of this project, it is important that the supplier selection process is flexible in order to support the management of that variability.

Collaboration between buyer and supplier is accomplished through the implementation of one of the suggested purchasing strategies in Chapter 3 and must be continuously assessed.

4.2 Supplier assessment and development

Supplier relationship assessment must be continuously performed based on data of every transaction between supplier and buyer.

In this project a three dimensional collaboration evaluation is proposed, as illustrated on Figure 4.2.

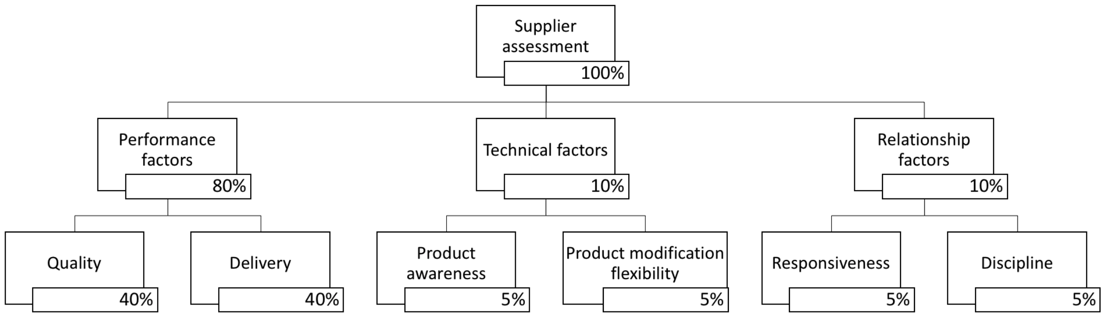

Figure 4.2: Structure of the proposed evaluation factors

These evaluation factors and their respective weights were proposed and discussed during a meeting with the logistics manager and the product development manager.

The most important factors for the assessment of a supplier are performance factors, namely quality and delivery, each one of these factors accounts for 40% of the total evaluation. Quality evaluation refers to the compliance of the supplied product to the buyer's imposed specifications and is obtained through the ratio of non-conformities detected in the products supplied. Delivery evaluation is calculated from the ratio of on-time deliveries.

Technical factors account for 10% of the total assessment grade. Technical factors are divided into two factors with the same weight distribution. Product awareness relates to the supplier's capability of suggesting improvements to the product, or better alternatives based on the supplier's technical expertise. Product modification flexibility is related to the supplier being able to introduce rapidly changes in a product or respond to punctual changes in the product.

Relationship factors account for the last 10% of the total supplier assessment. Responsiveness corresponds to how fluid is the communication between the two entities and discipline is related to the procedural compliment, i.e., evaluates if the supplier is consistent on how he handles the collaboration.

$$E = \left(0.4 \times \frac{Q_{QP}}{T_P} + 0.4 \times \frac{D_{OT}}{T_D} + 0.05 \times PA + 0.05 \times PM + 0.05 \times R + 0.05 \times D\right) \times 100 \quad (4.1)$$

where:

E = Total score of supplier

Q_{QP} = Total of conforming parts

T_P = Total of bought parts

D_{OT} = Total deliveries on time

T_D = Total deliveries

PA = Product awareness classification (between 0 and 100)

PM = Product modification flexibility classification (between 0 and 100)

R = Responsiveness classification (between 0 and 100)

D = Discipline classification (between 0 and 100)

Equation 4.1 demonstrates how the supplier's score can be obtained. The performance factors are obtained from historical data, while technical and relationship factors are obtained from empirical knowledge of the logistics manager, responsible for the suppliers assessment.

Depending on the strategic value of the component sold by the supplier the logistics manager must decide on whether to develop or not the supplier, i.e, if the supplier is the only one who sell or manufactures a certain item and presents recurrent quality issues or delays, then the buyer must implement a development program in order to improve the supplier's performance. If the supplier demonstrates several performance issues and the item supplied an be easily sourced from another supplier from the supplier pool, then the best path might be changing to another supplier.

4.3 Continuous Improvement

The continuous improvement process, as illustrated in Figure 1.1, closes the loop of the proposed system, magnifying the importance of not looking at the process of managing the procurement of materials as a static one. Continuous improvement is essential for a company to respond to a competitive and demanding market, focusing on cutting down costs, increasing productivity and overall company's performance.

The system proposed in this project must be continuously changed. Criteria must be redefined in order to keep up with new business demands and items consumption must be continuously monitored in order to manage and maintain the collaboration strategies.

The application of Plan, Do, Check, Act (PDCA) cycles is a suitable methodology to drive continuous improvement. This methodology is outlined in the following four steps:

- Plan – in this step are identified problems or matters than might need a solution or improvement. A set of solutions are discussed and an implementation plan is developed;
- Do – the solutions encountered in the previous step are tested;
- Check – in this step the results from the testing phase are analyzed;
- Act – this step corresponds to the adoption and implementation of the solution for the problem.

After the last step, the cycle goes back to the planning phase where a new encountered problem or an improvement on the last solution is discussed.

Chapter 5

Conclusions and Future Work

In this final Chapter, a reflection on the work developed over this project is carried out and suggestions for future work to be developed as a consequence of this initial approach are presented.

5.1 Reflection on the project

The company where this project was developed has implemented a mass customization strategy, creating interchangeable modules to be assembled in various machine model's and offering the client the capability of customizing the final product from a vast range of options. This shift of paradigm improved the image of the company on the eyes of the customer, but at the same time created multiple operational complications, namely difficulty in predicting the delivery date of an incoming order and difficulty to obey the previously stipulated delivery date of a machine demonstrating a certain inability to manage all the items required to assemble customized product variants. The difficulties exhibited by the company triggered the research questions present in the Introduction of this project.

The first question was answered in Chapter 3. In this chapter, a methodology was developed in order to classify the items required for the late customization phase of the manufacturing process of a standard machine. This methodology classified the items according to their consumption and to their criticality. The consumption classification was performed by the application of an ABC analysis based on the quantity of an item consumed over a year, while the criticality classification was performed by the application of a XYZ analysis based on the commonality index of an item. This kind of classification can be found in the literature applied to the classification of spare parts, but it is not usually utilized for the classification of manufacturing components. The combination of both analysis led to the grouping of the items into clusters containing items with similar consumption and criticality. Purchasing strategies for each group were presented.

The second question was answered in Chapter 3 and Chapter 4. The starting point of the segmentation is the purchasing strategy addressed to each item. In Chapter 4 a framework for the selection and assessment of suppliers was presented. This framework aims at selecting the most appropriate suppliers to collaborate with the company according to the purchasing strategy suggested by the application of the items classification methodology. The partner selection process consists in a course of action that lead to the establishment of a collaboration. The proposed process provides a collaboration assessment tool that allows the logistics manager to compare suppliers and identify the necessity of improving a supplier or replace it for a more suitable one.

Through the application of this methodology it is possible for the company to provide a fast time to market for every standard machine, since at least one of each type of optional equipment is readily available for delivery due to the partnerships established with suppliers for the selected items. If a fast delivery is a priority for the client then the company grants a set of optional equipment available for fast delivery.

5.2 Future work

All the research objectives outlined for this project were answered whereby in the future the proposed methodology can be implemented for all the different optional equipment types, since this project focused on the numerical controllers and the safety modules. Collecting data for the implementation of the methodology will constitute a challenge since the information is not grouped in one database and to quantify precisely what were the optional equipments installed in previously sold machines implicates crossing data from many sources. These adversities can demotivate the people involved in the project and create resistance to its implementation, so it would have a very significant impact in the company if there was a better integration between the product configurator software, the generation of the BOMs and the company's ERP.

The development of an information system (IS) that allowed the management of the system proposed in this project would be important to facilitate the task of managing suppliers. The IS would help the company to achieve shorter supply times and source superior quality materials.

The centralization of all the data required for the classification of the materials, definition of purchasing strategies and management of multiple supplier pools would foster collaboration with suppliers. The ability to easily manage multiple supplier pools is also a considerable advantage of the implementation of an IS, since it would expedite the partner selection process. The IS would have the hability to export data to a Business Analytics software like Microsoft Power BI, where a dashboard showing real-time data would show graphically supplier score, allow the comparison between suppliers, show key-performance-indicator such as total downtime minutes with the possibility to perform a drill-down operation in order to filter total downtime minutes by material, supplier, or machine produced. Also a total defect quantity indicator would be displayed and a similiar drill down operation (by material type, defect type) would be available.

Appendix A

ABC analysis

In this appendix the ABC analysis explored in Chapter 3 is demonstrated. Due to size and page limitations, the table had to be separated in half and is shown in the next 2 pages.

Item	Quantity	Lead Time	Total	%% acumulada quantidade	ABC
170510189	2	15	336	15%	A
170510220	2	15	136	21%	A
170510289	2	15	120	26%	A
171602002	1	15	87	30%	A
171109314	1	13	64	33%	A
170302304	1	16	63	36%	A
170302306	1	15	63	38%	A
170510190	2	15	60	41%	A
171306031	1	15	59	44%	A
NM1-0151-00-0684	1	7	50	46%	A
NM1-0151-00-0604	1	7	50	48%	A
NM2-0044-00-0010	1	15	49	50%	A
171111200	1	15	45	52%	A
NM1-0151-00-0400	4	7	44	54%	A
QU1-0304-0K-0081	1	15	42	56%	A
NM1-0151-00-0718	1	7	37	58%	A
NM1-0151-00-0708	1	7	37	59%	A
NM1-0151-00-0682	1	7	37	61%	A
NM1-0151-00-0602	1	7	37	63%	A
171808010	1	5	36	64%	A
171101520	1	25	35	66%	A
NM1-0151-00-0020	1	7	35	67%	A
171011034	1	8	35	69%	A
171808001	1	5	32	70%	A
171109318	1	16	28	71%	A
NM1-0151-00-0409	4	7	28	73%	A
QU1-0500-00-0032	1	10	23	74%	A
171101508	1	20	23	75%	A
QU2-0304-00-0095	1	8	23	76%	A
170305810	2	15	23	77%	A
NM1-0151-00-0719	1	4	22	78%	A
170111300	4	16	21	79%	A
170302008	1	15	20	80%	A
171101516	1	20	19	80%	B
171101517	1	20	19	81%	B
QU1-0304-00-013A	1	15	19	82%	B
QU2-0304-00-0036	1	5	19	83%	B
QU1-0304-0K-0087	1	15	17	84%	B
QU2-0304-00-0097	1	8	17	84%	B
171101509	1	20	16	85%	B
NM1-0151-00-0023	1	5	16	86%	B
QU1-0539-00-0101	1	10	16	86%	B
170302021	1	16	16	87%	B
171102291	4	16	16	88%	B
NM1-0151-00-0022	1	7	14	89%	B
171111201	1	15	14	89%	B
170302015	1	16	12	90%	B
171101430	1	20	11	90%	B
171101351	1	22	10	91%	B

QU1-0500-00-0034	1	10	10	91%	B
QU1-0304-00-0040	1	15	10	91%	B
NM1-0151-00-0016	1	7	10	92%	B
170111318	2	15	9	92%	B
170305904	1	5	8	93%	B
171601039	2	15	8	93%	B
171603031	2	15	8	93%	B
171102285	2	16	8	94%	B
170111710	2	15	8	94%	B
170111720	2	15	8	94%	B
171603036	2	16	8	95%	B
171603037	2	16	8	95%	B
171101177	1	20	7	95%	B
QU2-0304-00-0096	1	8	7	96%	C
171101271	1	25	6	96%	C
170111315	1	16	5	96%	C
171102261	1	16	4	96%	C
171101261	1	22	4	97%	C
171102270	1	15	4	97%	C
171102271	1	10	4	97%	C
171102280	1	16	4	97%	C
NM1-0151-00-0021	1	7	4	97%	C
NM2-0352-00-0140	1	10	4	97%	C
171102284	1	16	4	98%	C
170302903	1	15	4	98%	C
170302017	1	8	4	98%	C
170302018	1	8	4	98%	C
170302019	1	8	4	98%	C
170305906	1	8	4	99%	C
170302020	1	16	4	99%	C
171808004	1	5	4	99%	C
NM1-0151-00-0401	4	7	4	99%	C
170111290	4	20	4	99%	C
171102529	1	15	1	99%	C
171101558	1	45	1	99%	C
171101560	1	45	1	99%	C
171101518	1	16	1	99%	C
171105216	1	20	1	99%	C
170510287	1	20	1	100%	C
170510269	1	20	1	100%	C
NM1-0151-00-0001	1	7	1	100%	C
QU2-0304-00-0109	1	10	1	100%	C
170111301	1	15	1	100%	C
QU2-0304-00-0107	1	10	1	100%	C
QU2-0304-00-0108	1	10	1	100%	C
170506001	1	15	1	100%	C
NM2-0044-00-0003	1	15	1	100%	C
NM2-0011-00-0050	1	15	1	100%	C
NM2-0011-00-0132	1	15	1	100%	C
171102282	1	20	1	100%	C

Appendix B

Combination of ABC and XYZ Analysis

In this appendix the combination of both analysis explored in Chapter 3 is demonstrated. Due to size and page limitations, the table had to be separated in half and is shown in the next 2 pages.

Item	Qt.M	Lead Time	Total	ABC	BB3515	BB5020	QB13530	QB16040	QB22040	QN13530	QN16040	QN22040	Machines where used	Comunality	XYZ	Combination
170510189	2	15	336	A	0	42	154	28	112	0	0	0	4	0,5	Y	AY
170510220	2	15	136	A	8	20	56	16	36	0	0	0	5	0,625	X	AX
170510289	2	15	120	A	20	20	30	30	20	0	0	0	5	0,625	X	AX
171602002	1	15	87	A	20	17	11	3	8	16	4	8	8	1	X	AX
171109314	1	13	64	A	20	17	14	4	8	1	0	0	6	0,75	X	AX
170302304	1	16	63	A	20	17	13	4	9	0	0	0	5	0,625	X	AX
170302306	1	15	63	A	20	17	13	4	9	0	0	0	5	0,625	X	AX
170510190	2	15	60	A	4	4	28	8	16	0	0	0	5	0,625	X	AX
171306031	1	15	59	A	18	12	0	0	0	17	4	8	5	0,625	X	AX
NM1-0151-00-0684	1	7	50	A	0	0	11	3	8	16	4	8	6	0,75	X	AX
NM1-0151-00-0604	1	7	50	A	0	0	11	3	8	16	4	8	6	0,75	X	AX
NM2-0044-00-0010	1	15	49	A	14	9	13	4	9	0	0	0	5	0,625	X	AX
171111200	1	15	45	A	14	6	13	4	8	0	0	0	5	0,625	X	AX
NM1-0151-00-0400	4	7	44	A	0	16	0	0	0	20	4	4	4	0,5	Y	AY
QU1-0304-0K-0081	1	15	42	A	6	8	0	0	0	16	4	8	5	0,625	X	AX
NM1-0151-00-0718	1	7	37	A	20	17	0	0	0	0	0	0	2	0,25	Z	AZ
NM1-0151-00-0708	1	7	37	A	20	17	0	0	0	0	0	0	2	0,25	Z	AZ
NM1-0151-00-0682	1	7	37	A	20	17	0	0	0	0	0	0	2	0,25	Z	AZ
NM1-0151-00-0602	1	7	37	A	20	17	0	0	0	0	0	0	2	0,25	Z	AZ
171808010	1	5	36	A	0	27	0	0	9	0	0	0	2	0,25	Z	AZ
171101520	1	25	35	A	12	4	10	2	7	0	0	0	5	0,625	X	AX
NM1-0151-00-0020	1	7	35	A	12	4	10	2	7	0	0	0	5	0,625	X	AX
171011034	1	8	35	A	0	27	0	0	8	0	0	0	2	0,25	Z	AZ
171808001	1	5	32	A	0	24	0	0	8	0	0	0	2	0,25	Z	AZ
171109318	1	16	28	A	0	0	0	0	0	16	4	8	3	0,375	Y	AY
NM1-0151-00-0409	4	7	28	A	0	0	0	0	0	20	4	4	3	0,375	Y	AY
QU1-0500-00-0032	1	10	23	A	14	9	0	0	0	0	0	0	2	0,25	Z	AZ
171101508	1	20	23	A	6	4	0	0	0	6	1	6	5	0,625	X	AX
QU2-0304-00-0095	1	8	23	A	6	4	0	0	0	6	1	6	5	0,625	X	AX
170305810	2	15	23	A	0	16	0	0	7	0	0	0	2	0,25	Z	AZ
NM1-0151-00-0719	1	4	22	A	0	0	11	3	8	0	0	0	3	0,375	Y	AY
170111300	4	16	21	A	0	12	0	0	4	0	5	0	3	0,375	Y	AY
170302008	1	15	20	A	0	15	0	0	5	0	0	0	2	0,25	Z	AZ
171101516	1	20	19	B	0	0	10	2	7	0	0	0	3	0,375	Y	BY
171101517	1	20	19	B	0	0	10	2	7	0	0	0	3	0,375	Y	BY
QU1-0304-00-013A	1	15	19	B	0	0	10	2	7	0	0	0	3	0,375	Y	BY
QU2-0304-00-0036	1	5	19	B	0	0	10	2	7	0	0	0	3	0,375	Y	BY
QU1-0304-0K-0087	1	15	17	B	12	4	0	0	0	1	0	0	3	0,375	Y	BY
QU2-0304-00-0097	1	8	17	B	12	4	0	0	0	1	0	0	3	0,375	Y	BY
171101509	1	20	16	B	12	4	0	0	0	0	0	0	2	0,25	Z	BZ
NM1-0151-00-0023	1	5	16	B	12	4	0	0	0	0	0	0	2	0,25	Z	BZ
QU1-0539-00-0101	1	10	16	B	12	4	0	0	0	0	0	0	2	0,25	Z	BZ
170302021	1	16	16	B	0	12	0	0	4	0	0	0	2	0,25	Z	BZ
171102291	4	16	16	B	0	12	0	0	4	0	0	0	2	0,25	Z	BZ
NM1-0151-00-0022	1	7	14	B	6	8	0	0	0	0	0	0	2	0,25	Z	BZ
171111201	1	15	14	B	6	8	0	0	0	0	0	0	2	0,25	Z	BZ
170302015	1	16	12	B	0	9	0	0	3	0	0	0	2	0,25	Z	BZ
171101430	1	20	11	B	0	4	0	0	0	5	1	1	4	0,5	Y	BY
171101351	1	22	10	B	2	2	3	2	1	0	0	0	5	0,625	X	BX
QU1-0500-00-0034	1	10	10	B	6	4	0	0	0	0	0	0	2	0,25	Z	BZ
QU1-0304-00-0040	1	15	10	B	2	2	3	2	1	0	0	0	5	0,625	X	BX
NM1-0151-00-0016	1	7	10	B	2	2	3	2	1	0	0	0	5	0,625	X	BX
170111318	2	15	9	B	0	6	0	0	2	0	1	0	3	0,375	Y	BY
170305904	1	5	8	B	0	6	0	0	2	0	0	0	2	0,25	Z	BZ
171601039	2	15	8	B	4	4	0	0	0	0	0	0	2	0,25	Z	BZ
171603031	2	15	8	B	4	4	0	0	0	0	0	0	2	0,25	Z	BZ
171102285	2	16	8	B	0	6	0	0	2	0	0	0	2	0,25	Z	BZ
170111710	2	15	8	B	0	6	0	0	2	0	0	0	2	0,25	Z	BZ
170111720	2	15	8	B	0	6	0	0	2	0	0	0	2	0,25	Z	BZ
171603036	2	16	8	B	4	4	0	0	0	0	0	0	2	0,25	Z	BZ
171603037	2	16	8	B	4	4	0	0	0	0	0	0	2	0,25	Z	BZ
171101177	1	20	7	B	0	0	0	0	0	5	1	1	3	0,375	Y	BY
QU2-0304-00-0096	1	8	7	C	0	0	0	0	0	5	1	1	3	0,375	Y	CY
171101271	1	25	6	C	0	0	3	2	1	0	0	0	3	0,375	Y	CY
170111315	1	16	5	C	0	3	0	0	1	0	1	0	3	0,375	Y	CY
171102261	1	16	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
171101261	1	22	4	C	2	2	0	0	0	0	0	0	2	0,25	Z	CZ
171102270	1	15	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
171102271	1	10	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
171102280	1	16	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
NM1-0151-00-0021	1	7	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
NM2-0352-00-0140	1	10	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
171102284	1	16	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170302903	1	15	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170302017	1	8	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170302018	1	8	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170302019	1	8	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170305906	1	8	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
170302020	1	16	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
171808004	1	5	4	C	0	3	0	0	1	0	0	0	2	0,25	Z	CZ
NM1-0151-00-0401	4	7	4	C	0	0	0	0	0	0	4	0	1	0,125	Z	CZ
170111290	4	20	4	C	0	0	0	0	0	0	4	0	1	0,125	Z	CZ
171102529	1	15	1	C	0	0	0	0	0	0	1	0	1	0,125	Z	CZ
171101558	1	45	1	C	0	0	1	0	0	0	0	0	1	0,125	Z	CZ
171101560	1	45	1	C	0	0	1	0	0	0	0	0	1	0,125	Z	CZ
171101518	1	16	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
171105216	1	20	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
170510287	1	20	1	C	0	0	0	0	0	0	1	0	1	0,125	Z	CZ
170510269	1	20	1	C	0	0	0	0	0	0	1	0	1	0,125	Z	CZ
NM1-0151-00-0001	1	7	1	C	0	0	1	0	0	0	0	0	1	0,125	Z	CZ
QU2-0304-00-0109	1	10	1	C	0	0	0	0	0	0	1	0	1	0,125	Z	CZ
170111301	1	15	1	C	0	0	0	0	0	0	1	0	1	0,125	Z	CZ
QU2-0304-00-0107	1	10	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
QU2-0304-00-0108	1	10	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
170506001	1	15	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
NM2-0044-00-0003	1	15	1	C	0	0	1	0	0	0	0	0	1	0,125	Z	CZ
NM2-0011-00-0050	1	15	1	C	0	0	1	0	0	0	0	0	1	0,125	Z	CZ
NM2-0011-00-0132	1	15	1	C	0	0	0	0	0	1	0	0	1	0,125	Z	CZ
171102282	1	20	1	C	0	0	0	0	1	0	0	0	1	0,125	Z	CZ

References

[1] Martin Rudberg and Joakim Wikner. Mass customization in terms of the customer order decoupling point. *Production Planning and Control*, 15(4):445–458, 2004. doi:10.1080/0953728042000238764.

[2] F Robert Jacobs and R Ichard B Chase. *Operations and Supply Management: The Core*. 2008.

[3] M. Hoppe. *Inventory Optimization with SAP*. SAP press. Galileo Press, 2008. URL: https://books.google.pt/books?id=64GhbwAACAAJ.

[4] Nikolaos Kourentzes. ABC-XYZ analysis for forecasting, 2016. URL: http://http://kourentzes.com/forecasting/2016/10/15/abc-xyz-analysis-for-forecasting/.

[5] Prof. Dr.-Ing Bernd Noche. Abc-/xyz analysis introduction. Presentation, 2016.

[6] Thomas Ditlev Brunoe, Ann-Louise Andersen, and Kjeld Nielsen. Reconfigurable manufacturing systems in small and medium enterprises. In Jocelyn Bellemare, Serge Carrier, Kjeld Nielsen, and Frank T. Piller, editors, *Managing Complexity*, pages 205–213, Cham, 2017. Springer International Publishing.

[7] H. ElMaraghy, G. Schuh, W. Elmaraghy, F. Piller, P. Schönsleben, M. Tseng, and A. Bernard. Product variety management. *CIRP Annals - Manufacturing Technology*, 62(2):629–652, 2013. arXiv:arXiv:1011.1669v3, doi:10.1016/j.cirp.2013.05.007.

[8] S. J. Hu, J. Ko, L. Weyand, H. A. Elmaraghy, T. K. Lien, Y. Koren, H. Bley, G. Chryssolouris, N. Nasr, and M. Shpitalni. Assembly system design and operations for product variety. *CIRP Annals - Manufacturing Technology*, 60(2):715–733, 2011. doi:10.1016/j.cirp.2011.05.004.

[9] Yoram Koren. *The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems*. 2010. arXiv:arXiv:1011.1669v3, doi:10.1002/9780470618813.

[10] Jongyung Park, Kitae Shin, Tai-Woo Chang, and Jinwoo Park. An integrative framework for supplier relationship management. *Industrial Management & Data Systems*, 110(4):495–515, 2010. URL: https://doi.org/10.1108/02635571011038990, arXiv:https://doi.org/10.1108/02635571011038990, doi:10.1108/02635571011038990.

[11] Leontin K. Grafmüller and Hagen Habicht. *Current Challenges for Mass Customization on B2B Markets*, pages 269–279. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4_21.

[12] Christopher W L Hart. Mass customization: conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management*, 6(2):36–45, 1995.

[13] J.H. Gilmore and B.J. Pine. *Markets of One: Creating Customer-unique Value Through Mass Customization*. Harvard business review book series. Harvard Business School Press, 2000. URL: https://books.google.pt/books?id=zag1jH5BR7gC.

[14] Fabrizio Salvador, Pablo Martin de Holan, and Frank T Piller. Cracking the Code of Mass Customization. *MIT Sloan Management Review*, 50(3):71–78, 2009. URL: http://sloanreview.mit.edu/article/cracking-the-code-of-mass-customization/.

[15] Kjeld Nielsen, Thomas Ditlev Brunoe, Kim Noergaard Jensen, and Ann-Louise Andersen. *Utilization of Mass Customization in Construction and Building Industry*, pages 115–125. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4{_}9, doi:10.1007/978-3-319-29058-4_9.

[16] Stig B. Taps, Thomas Ditlev, and Kjeld Nielsen. *Mass Customization in SMEs: Literature Review and Research Directions*, pages 195–203. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4_15, doi:10.1007/978-3-319-29058-4_15.

[17] Maria K. Thomassen and Erlend Alfnes. *Mass Customization Challenges of Engineer-to-Order Manufacturing*, pages 27–39. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4_3, doi:10.1007/978-3-319-29058-4_3.

[18] Frank T. Piller. Mass customization: Reflections on the state of the concept. *International Journal of Flexible Manufacturing Systems*, 16(4 SPEC. ISS.):313–334, 2004. doi:10.1007/s10696-005-5170-x.

[19] Aldo Duchi, Filippo Tamburini, Daniele Parisi, Omid Maghazei, and Paul Schönsleben. *From ETO to Mass Customization: A Two-Horizon ETO Enabling Process*, pages 99–113. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4_8, doi:10.1007/978-3-319-29058-4_8.

[20] F. Salvador and C. Forza. Configuring products to address the customization-responsiveness squeeze: A survey of management issues and opportunities. *International Journal of Production Economics*, 91(3):273–291, 2004. doi:10.1016/j.ijpe.2003.09.003.

[21] A.K.W. Lau and R.C.M. Yam. A case study of product modularization on supply chain design and coordination in hong kong and china. *Journal of Manufacturing Technology Management*, 16(4):432–446, 2005. URL: https://doi.org/10.1108/17410380510594516, arXiv:https://doi.org/10.1108/17410380510594516, doi:10.1108/17410380510594516.

[22] B.J. Pine. *Mass Customization: The New Frontier in Business Competition*. Harvard Business School Press, 1993. URL: https://books.google.pt/books?id=Seli55Gt-sEC.

[23] F. Salvador, C. Forza, and M. Rungtusanatham. Modularity, product variety, production volume, and component sourcing: Theorizing beyond generic prescriptions. *Journal of Operations Management*, 20(5):549–575, 2002. doi:10.1016/S0272-6963(02)00027-X.

[24] Karl Ulrich. The role of product architecture in the manufacturing firm. *Research Policy*, 24(3):419–440, 1995. arXiv:arXiv:1011.1669v3, doi:10.1016/0048-7333(94)00775-3.

[25] C Alexander. *Notes of the Synthesis of Form*. 1964.

[26] Ricardo Ernst and Bardia Kamrad. Evaluation of supply chain structures through modularization and postponement. *European Journal of Operational Research*, 124(3):495 – 510, 2000. URL: http://www.sciencedirect.com/science/article/pii/S0377221799001848, doi:https://doi.org/10.1016/S0377-2217(99)00184-8.

[27] Desmond Doran. Supply chain implications of modularization. *International Journal of Operations & Production Management*, 23(3):316–326, 2003. URL: https://doi.org/10.1108/01443570310462785, arXiv:https://doi.org/10.1108/01443570310462785, doi:10.1108/01443570310462785.

[28] M. Sako. The essence of success in supplier development: the japanese experience. *JAMA Forum*, 39(2), 1999.

[29] Susan W Sanderson and Vic Uzumeri. Strategies for new product development and renewal: design-based incrementalism. 1990.

[30] R. I. Van Hoek. Rediscovery of postponement a literature review and directions for research. *Journal of Operations Management*, 19(2):161–184, 2001. doi:10.1016/S0272-6963(00)00057-7.

[31] Wroe Alderson. Marketing efficiency and the principle of postponement. In *A Twenty-First Century Guide to Aldersonian Marketing Thought*, pages 109–113. 2006. doi:10.1007/0-387-28181-9_8.

[32] Remko I. van Hoek. The thesis of leagility revisited. *International Journal of Agile Management Systems*, 2(3):196–201, 2000. URL: http://www.emeraldinsight.com/doi/10.1108/14654650010356103, doi:10.1108/14654650010356103.

[33] Kemal Caglar Can. Postponement, mass customization, modularization and customer order decoupling point: Building the model of relationships. 01 2008.

[34] Hau L. Lee, Corey Billington, and Brent Carter. Hewlett-packard gains control of inventory and service through design for localization. *Interfaces*, 23(4):1–11, 1993. URL: https://doi.org/10.1287/inte.23.4.1, arXiv:https://doi.org/10.1287/inte.23.4.1, doi:10.1287/inte.23.4.1.

[35] Jan Olhager. Strategic positioning of the order penetration point. 85:319–329, 02 2003.

[36] Martin Bonev, Anna Myrodia, and Lars Hvam. *Reconfiguring Variety, Profitability, and Postponement for Product Customization with Global Supply Chains*, pages 13–26. Springer International Publishing, Cham, 2017. URL: https://doi.org/10.1007/978-3-319-29058-4_2, doi:10.1007/978-3-319-29058-4_2.

[37] Andrew Kusiak. Integrated product and process design: A modularity perspective. *Journal of Engineering Design*, 13(3):223–231, 2002. URL: https://doi.org/10.1080/09544820110108926, arXiv:https://doi.org/10.1080/09544820110108926, doi:10.1080/09544820110108926.

[38] J. H. Mikkola and O. Gassmann. Managing modularity of product architectures: toward an integrated theory. *IEEE Transactions on Engineering Management*, 50(2):204–218, May 2003. doi:10.1109/TEM.2003.810826.

[39] Cipriano Forza, Fabrizio Salvador, and Alessio Trentin. Form postponement effects on operational performance: a typological theory. *International Journal of Operations & Production Management*, 28(11):1067–1094, 2008. URL: https://doi.org/10.1108/01443570810910197, arXiv:https://doi.org/10.1108/01443570810910197, doi:10.1108/01443570810910197.

[40] Dinesh Dhoka and Lokeswara Y. Choudary. Challenges with multi-dimensional inventory classifications and optimization. *Asian Social Science*, 11(4):365–370, 2015. doi:10.5539/ass.v11n4p365.

[41] J. Stoll, R. Kopf, J. Schneider, and G. Lanza. Criticality analysis of spare parts management: a multi-criteria classification regarding a cross-plant central warehouse strategy. *Production Engineering*, 9(2):225–235, Apr 2015. URL: https://doi.org/10.1007/s11740-015-0602-2, doi:10.1007/s11740-015-0602-2.

[42] Marcello Braglia, Andrea Grassi, and Roberto Montanari. Multi-attribute classification method for spare parts inventory management. *Journal of Quality in Maintenance Engineering*, 10(1):55–65, 2004. URL: https://doi.org/10.1108/13552510410526875, arXiv:https://doi.org/10.1108/13552510410526875, doi:10.1108/13552510410526875.

[43] Ludo F. Gelders and Paul M. Van Looy. An inventory policy for slow and fast movers in a petrochemical plant: A case study. *The Journal of the Operational Research Society*, 29(9):867–874, 1978. URL: http://www.jstor.org/stable/3009559.

[44] R. Dekker, M.J. Kleijn, and P.J. de Rooij. A spare parts stocking policy based on equipment criticality. *International Journal of Production Economics*, 56-57:69 – 77, 1998. Production Economics: The Link Between Technology And Management. URL: http://www.sciencedirect.com/science/article/pii/S0925527397000509, doi:https://doi.org/10.1016/S0925-5273(97)00050-9.

[45] Eric Porras and Rommert Dekker. An inventory control system for spare parts at a refinery: An empirical comparison of different re-order point methods. *European Journal of Operational Research*, 184(1):101–132, January 2008. URL: https://ideas.repec.org/a/eee/ejores/v184y2008i1p101-132.html.

[46] Poorwar Wandalkar, Pt Pandit, and Ar Zite. ABC and VED analysis of the drug store of a tertiary care teaching hospital. *Indian Journal of Basic and Applied Medical Research*, 3(1):126–131, 2013.

[47] Ander Errasti, Claudia Chackelson, and Raul Poler. An expert system for inventory replenishment optimization. In Ángel Ortiz, Rubén Darío Franco, and Pedro Gómez Gasquet, editors, *Balanced Automation Systems for Future Manufacturing Networks*, pages 129–136, Berlin, Heidelberg, 2010. Springer Berlin Heidelberg.

[48] Dinesh Kumar Dhoka and Y Lokeswara Choudary. “XYZ” Inventory Classification & Challenges. *IOSR Journal of Economics and Finance*, 2(2):23–26, 2013.

[49] Gerald Reiner and Michael Trcka. Customized supply chain design: Problems and alternatives for a production company in the food industry. a simulation based analysis. *International Journal of Production Economics*, 89(2):217 – 229, 2004. Supply Chain Management. URL: http://www.sciencedirect.com/science/article/pii/S0925527303000549, doi:https://doi.org/10.1016/S0925-5273(03)00054-9.

[50] D Simchi-Levi, Philip Kaminsky, and E Simchi-Levi. *Designing and managing the supply chain: concepts, strategies, and case studies*, volume 1. 2003. URL: http://books.google.com/books?id=SYKYU06odPgC.

[51] Charu Chandra and Sameer Kumar. Supply chain management in theory and practice: a passing fad or a fundamental change? *Industrial Management & Data Systems*, 100(3):100–114, 2000. URL: http://www.emeraldinsight.com/doi/10.1108/02635570010286168, doi:10.1108/02635570010286168.

[52] Laura B Forker and Peter Stannack. Cooperation versus competition: do buyers and suppliers really see eye-to-eye? *European Journal of Purchasing & Supply Management*, 6(1):31–40, 2000. doi:10.1016/S0969-7012(99)00032-5.

[53] Charles a. Weber, John R. Current, and W.C. Benton. Vendor selection criteria and methods. *European Journal of Operational Research*, 50(1):2–18, 1991. doi:10.1016/0377-2217(91)90033-R.

[54] Marc J. Schniederjans and Tim Garvin. Using the analytic hierarchy process and multi-objective programming for the selection of cost drivers in activity-based costing. *European Journal of Operational Research*, 100(1):72 – 80, 1997. URL: http://www.sciencedirect.com/science/article/pii/S0377221796003025, doi:https://doi.org/10.1016/S0377-2217(96)00302-5.

[55] Martin Christopher. *Logistics and supply chain management*, volume 4. 2011. doi:10.1016/j.retrec.2012.10.006.

[56] Filip Roodhooft and Jozef Konings. Vendor selection and evaluation an activity based costing approach. *European Journal of Operational Research*, 96(1):97–102, 1997. doi:10.1016/0377-2217(95)00383-5.